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CHARACTERIZATION OF COMBUSTION PRODUCTS OF MILITARY PROPELLANTS

FINAL REPORT

Volume II

by

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March 1983

Supported by:

U.S. Army Medical Research and Development Command Fort Detrick, Frederick, Maryland 21701-5012

Contract No. DAMD17-80-C-0019

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8c ADDRESS (C	ity, State, and	ZIP Code)		10. SOURCE OF	FUNDING NUMBER	s	
Fort De Frederi	trick ck, MD 21	701-5012		PROGRAM ELEMENT NO. 62777A	PROJECT NO. 3E1- 62777A846	TASK NO. 00	WORK UNIT ACCESSION NO 001
11. TITLE (Inclu	ide Security Cl	assification)					
Charact	erization	of Combustion	Products of Mi	litary Prope	llants, Volu	me II	
12. PERSONAL Snelson		incipal Inves	tigator; Ase, Pa	aul; Bock, W	arren; and B	utler, Ror	nald
13a. TYPE OF Final	REPORT Volume II	13b. TIME CO FROM <u>80</u>	OVERED Feb 1 TO 83 Mar 31	14. DATE OF REPO 1983 Mai	ORT <i>(Year, Month, .</i> rch	Day) 15. PAC	GE COUNT
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17.	COSATI	CODES	18. SUBJECT TERMS (Continue on reven	se if necessary and	d identify by b	olock number)
FIELD	GROUP	SUB-GROUP	Propellant com	mbustion pro	ducts; major	, minor, a	and trace
06	21		species. Exp	erimental la	boratory and	field stu	udies. (over
06	10		1		-		

16. (Continued)

combustion products. Volume I contains the main findings of the theoretical, laboratory, and field studies devoted to the characterization of combustion products of military propellants.

18. (Continued)

Simulated propellant combustor. M16 rifle. XM2 Fighting Vehicle, M198 howitzer, and MLRS. Theoretical product distribution calculations.

FOREWORD

IIT Research Institute is pleased to submit this two-volume document as the final report on the "Characterization of Combustion Products from Military Propellants." The study was sponsored by the U.S. Army Medical Bioengineering Research and Development Laboratory under Contract DAMD17-80-C-0019. The program started in February 1980 and the experimental phases ended in October 1982. The report contains much new information on the nature and amounts of combustion products formed in propellant systems not heretofore available.

We would like to acknowledge the enthusiasm and support received from Dr. William Dennis and Captain James W. Carroll of the U.S. Army Medical Bioengineering Research and Development Laboratory during the course of the program. The kind assistance of Dr. Eli Freedman, of the Interior Ballistics Division, Ballistics Research Laboratory, Aberdeen Proving Grounds, in providing theoretical performance calculations on the M6 propellant is also appreciated.

Citation of commercial organizations and trade names in this report does not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

Respectfully submitted, IIT RESEARCH INSTITUTE

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APPENDIX I

SUMMARY OF PROPELLANT COMBUSTION PRODUCT DATA OBTAINED IN THE LITERATURE SEARCH

SUMMARY OF PROPELLANT COMBUSTION PRODUCT DATA FROM LITERATURE SEARCH

1. Detonation Calculations (Special Technical Report No. 13)

Department of the Army, Edgewood Arsenal Contract DA-18-035-AMC-122(A), 1967. AD822301.

This report is largely concerned with the origins of muzzle flash. The propellants listed in Table 1 were considered.

TABLE 1. CALCULATION INPUT PARAMETERS FOR PURE EXPLOSIVES

		_	_	Crystal	Heat Forma	
Chemical Name	Formula	Formula Weight	Oxygen Balance ^a	Density, g/cc	kcal/ mol	kcal/g
Pentaerythitol tetra- nitrate (PETN)	C ₅ H ₈ N ₄ O ₁₂	316.2	-10.0	1.77	-125.0	-0.395
Cyclotrimethylene- trinitramine (RDX)	C ₃ H ₆ N ₆ O ₆	222.1	-22.0	1.80	+14.71	+0.066
Cyclotetramethylene- tetranitramine (HMX)	C4 H8 N8 O8	296.2	-22.0	1.90	+17.93	+0.061
Trinitrotoluene (TNT)	C7 H5 N3 O6	227.1	-74.0	1.64	-17.81	-0.078
Ammonium perchlorate (AP)	NH4 C1 O4	117.5	+34.1 ^b	1.95	-69.42	-0.591
Ammonium nitrate (AN)	NH4 NO3	80.0	+20.0	1.73	-87.27	-1.091

a Oxygen balance = $-\frac{1600}{\text{formula wt}}$ [2 C atoms + $\frac{\text{H}}{2}$ atom - 0 atom].

Theoretical product compositions were calculated using two models (LASL and SRI). Typical results are shown in Table 2. In one case the calculated combustion product compositions were compared with some experimental values obtained by the author. No details of the experimental methods were given. The results are shown in Table 3.

b Assuming C1 atoms form HC1.

TABLE 2. CALCULATED PRODUCT COMPOSITIONS [Mole%]

	ΗΜ ρ _o = 1	X, .6 g/cc	ρ ₀ = 1	T, .6 g/cc		T, .6 g/cc		X, .6 g/cc
Product	LASL	SRI	LASL	SRI	LASL	SRI	LASL	SRI
CO ₂	15.9	17.8	14.3	13.4	11.4	17.1	16.5	18.0
CO	1.5	2.6	2.1	1.3	9.5	7.7	0.2	1.0
CH4		1.4		2.7		3.2		0.8
C(s)	15.9	14.2	46.7	44.1	42.8	40.2	16.5	14.4
H ₂ O	33.3	30.6	22.7	17.7	22.4	16.6	33.3	31.3
H ₂					0.2	0.3		
NH ₃		1.2		0.7		0.7		0.9
N ₂	33.3	32.2	13.6	14.1	13.6	14.3	33.3	33.7

TABLE 3. COMPARISON OF CALCULATED AND EXPERIMENTAL EXPANDED PRODUCT COMPOSITIONS FOR PETN

Product	Exper Confined	imental Unconfined	Calcul for Detonat		Calculated for BKW Isentrope at 1500-1800K
ρ _o (g/cc)	1.74	1.74	1.77	1.00	1.74
Products (mole/mole P	ETN)			•	
CO ₂	3.39	3.50	3.95	3.04	4.0-4.1
CO	1.69	1.56	0.096	0.96	0.5-0.6
CH4	0.003	<0.0002	<0.0002	0.0002	0.3-0.4
C(s)	None	None	0.951	None	None
H ₂ O	3.50	3.45	4.00	3.94	3.2-3.3
H ₂	0.45	0.51	<0.0002	0.050	0.02-0.05
NH ₃	0.037	<0.0002	<0.0002	0.004	0.04-0.06
N ₂	2.00	2.00	2.00	1.99+	2.0

2. Solid Propellant Combustion Gas Analysis Using a Micrometer Technique

U.S. Air Force, Edwards Air Force Base Contract AFRPL-TR-69-53, 1969. AD851089.

The combustion products from two composite formulations containing 16% Al, 68% NH₄ClO₄, and 16% unspecified binder and 15% Al, 30% NH₄ClO₄, and 55% unspecified binder, were determined experimentally. A small microcombustor shown in Figure 1 was vented into a large chamber at reduced pressure (250 mm Hg) containing either argon or air. The contained effluents were then analyzed directly by a mass spectrometer within a period of 30 s. Typical results are shown in Tables 4 and 5.

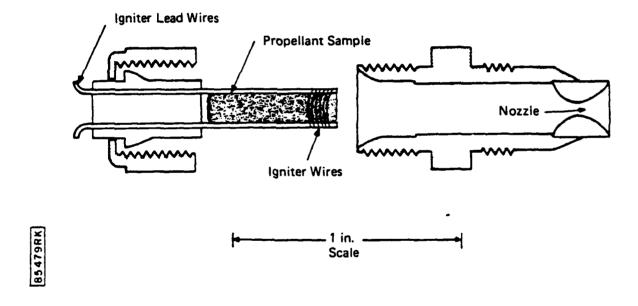


Figure 1. Micromotor design.

TABLE 4. COMPOSITE PROPELLANT FIRED IN ARGON [Composition in Mole%]

			Run	No.				Thermo- dynamic
Species	10197A	10197B	10207A	10207B	11027A	11027B	Average	
NH ₃	13.7	13.0	19.7	20.0	11.5	11.7	14.7	
H ₂ 0	30.8	22.3	36.9	21.9	12.8	29.6	25.3	19.2
CO	20.1	31.5	15.7	24.2	41.8	20.9	25.3	40.6
N ₂	7.2	11.6	5.7	10.0	14.6	7.0	9.2	12.9
HC1	27.1	20.0	20.9	22.4	15.9	29.2	23.8	24.4
CO ₂	1.1	1.6	1.0	1.4	3.3	1.6	1.7	3.0

TABLE 5. MODIFIED DOUBLE-BASE PROPELLANT FIRED IN AIR AND ARGON [Composition in Mole%]

Species	Air	Argon	Thermodynamic Prediction
NH ₃	2.7	14.4	
H ₂ 0	28.4	17.9	22.5
CO	9.3	33.8	47.2
N ₂	33.9	17.8	14.3
NO	2.2	3.6	
HC 1	5.2	10.4	10.1
CU ₂	18.4	7.1	5.9

Figure 2. Combustion products decay in air diluent.

85480RK

3. The Composition of the Exhaust Products of Military Weapons—A Comparison of Calculated and Experimental Results

Joint USAARL-USAFA Report, USAFA Report R-1968 1970. AD 871485.

The three propellant systems shown in Table 6 were the subject of the investigation described in the project title. An initial literature search, presumably made in the literature prior to 1970, revealed no relevant data on the systems below. Experimental arrangements for sampling gun and rocket propellant system effluents were constructed as indicated in Figures 3 and 4. Chemical analyses were also made by mass spectrometry on the collected species. Aerosols were collected, but it is not clear if they were chemically analyzed.

TABLE 6. PROPELLANT AND WEAPON SYSTEMS

Weapon	7.62mm Machine Gun	Caliber .50 Machine Gun	2.75 in. FFAR
Ammunition	Cartridge, 7.62mm, NATO	Cartridge, Caliber .50,	
Ball	M80	М33	
Propellant Charge Weight	WC846 2.92 g	WC860 15.99 g	N-5 2.68 kg
		Component, %	
	WC846	WC860	N-5
Nitrocellulose	82.61 ^a	80.54 ^a	49.7
% Nitrogen	13.12	13.15	12.6
Nitroglycerine	9.86 ^a	8.79 ^a	35.2
Diphenylamine	0.97ª	0.94 ^a	
Dinitrotoluene	0.57 ^a		
Graphite	0.2	0.2	
Moisture	0.62	1.13	
Volatiles	0.37	0.37	
Dibutylphthalate	5.07 ^a	8.11 ^a	
Diethylphthalate			10.5
2-Nitrodiphenylamine			2.0
Wax			0.2

0.07ª

 0.62^{a}

Sodium sulfate

Lead salicylate

Calcium carbonate

Potassium nitrate

Lead 2-ethylhexoate

0.12a

0.49a

0.73ª

1.3

1.1

^aReported on a volatile-free basis.

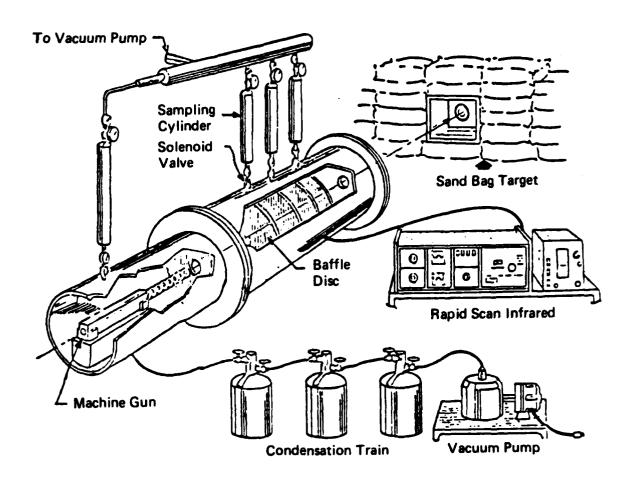


Figure 3. Gun exhaust sampling apparatus and test stand.



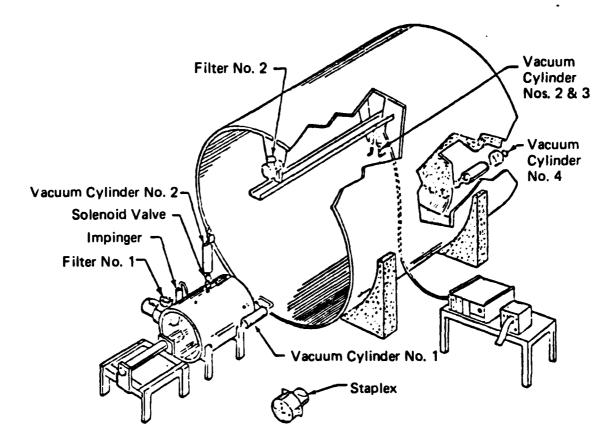


Figure 4. Rocket exhaust sampling apparatus and test stand.

The specific computer program used in the theoretical equilibrium calculations was not identified. The data base was the then existing JANNAF tables. To simplify the calculation, the primer compositions, added stabilizers, or smoke suppressants were not included in the computation.

The results from the study are essentially summarized by the data presented in Tables 7 through 14. In Table 15, the chemical species introduced into the computer computation are presented. It is at once apparent that a number of the species found experimentally, SCO, CH_3CHO , and C_6H_6 were not included in the computer data base.

COMPARISON OF RECONCILED COMPUTER AND EXPERIMENTAL RESULTS FOR SELECTED EXHAUST COMPONENTS OF THE 2.75 in. ROCKET USING N.5 PROPELLANT [Mole Fractions] TABLE 7.

		Calcul	Calculated Pressure, psi	sure, psi		Experi	Experimental
Component	1,200	1,000	200	100	14.7	Mean	Maximum
00	0.83E-00	0.83E-00	0.81E-00	0.76E-00	0.65E-00	0.21E-00	0.57E-00
C 02	0.16E-00	0.16E-00	0.18E-00	0.23E-00	0.34E-00	0.52E-00	0.70E-00
₹	0.73E-06	0.80E-06	0.13E-05	0.16E-05	0.37E-02	0.60E-02	0.26E-01
NH3	0.51E-04	0.31E-04	0.26E-04	0.24E-04	0.41E-04	0.70E-02	0.11E-01
N02	Exponents	range from	-10 (1200	-10 (1200 psi) to -26 (14.7 psi)	(14.7 psi)	None detected	tected
HCN	0.19E-04	0.16E-04	0.94E-05	0.30E-05	0.11E-05	0.30E-02	0.38E-02

COMPARISON OF RECONCILED COMPUTER AND EXPERIMENTAL RESULTS FOR SELECTED EXHAUST COMPONENTS OF THE 7.62mm MACHINE GUN USING WC846 PROPELLANT [Mole Fractions] TABLE 8.

		ن	alculated	Pressure,	psi		Experimental	mental
Component	50,000	25,000	25,000 10,000 5,000 1,000 14.7	5,000	1,000	14.7	Mean	Maximum
00	0.83E-00	0.80E-00	0.80E-00 0.78E-00 0.74E-00 0.63E-00 0.28E-00	0.74E-00	0.63E-00	0.28E-00	0.46E-00	0.81E-00
c0 ₂	0.18E-00	0.20E-00	0.20E-00 0.22E-00 0.25E-00 0.34E-02 0.68E-00	0.25E-00	0.34E-02	0.68E-00	0.26E-00	0.42E-00
CH *	0.91E-03	0.14E-02	0.14E-02 0.35E-02 0.84E-02 0.39E-01 0.46E-01	0.84E-02	0.39E-01	0.46E-01	0.10E-01	0.15E-01
NH ₃	0.12E-02	0.98E-03	0.98E-03 0.83E-03 0.76E-03 0.51E-03 0.11E-03	0.76E-03	0.51E-03	0.11E-03	0.38E-02	0.10E-01
NO ₂	Exponent	s range fr	Exponents range from -11 (50,000 psi) to -30 (14.7 psi)	,000 psi)	to -30 (14	.7 psi)	0.20E-02	N.48E-02
HCN	0.65E-03	0.36E-03	0.36E-03 0.18E-03 0.10E-03 0.25E-04 0.23E-06	0.10E-03	0.25E-04	0.23E-06	0.55E-03	0.10E-02

COMPARISON OF RECONCILED COMPUTER AND EXPERIMENTAL RESULTS FOR SELECTED EXHAUST COMPONENTS OF THE CALIBER .50 MACHINE GUN USING WC860 PROPELLANT [Mole Fractions] TABLE 9.

			משו	LAUTE FRACTIONIS	ſsu		•	
		3	alculated	Calculated Pressure, psi	psi		Experimental	mental
Component	20,000	25,000	10,000	25,000 10,000 5,000 1,000 14.7	1,000	14.7	Mean	Maximum
00	0.83E-00	0.82E-00	0.78E-00	0.82E-00 0.78E-00 0.73E-00 0.60E-00 0.26E-00	0.50E-00	0.26E-00	0.65E-00	0.85E-00
c0 ₂	0.15E-00	0.17E-00	0.21E-00	0.17E-00 0.21E-00 0.24E-00 0.24E-00 0.67E-00	0.24E-00	0.47E-00	0.27E-00	0.59E-00
CH.	0.68E-02	0.11E-01	0.23E-01	0.11E-01 0.23E-01 0.37E-02 0.67E-01 0.55E-01	0.67E-01	0.55E-01	0.65E-02	0.93E-02
NH3	0.21E-02	0.17E-02	0.13E-02	0.17E-02 0.13E-02 0.11E-02 0.56E-03 0.12E-03	0.56E-03	0.12E-03	0.28E-02	0.80E-02
N02	Exponent	Exponents range from -12 (50000 psi) to -30 (14.7 psi)	от -12 (50	000 psi) t	0 -30 (14.	7 psi)	0.20E-03	0.50E-03
HCN	0.10E-02	0.55E-03	0.24E-03	0.55E-03 0.24E-03 0.13E-03 0.25E-04 0.20E-06	0.25E-04	0.20E-06	0.28E-03	0.8RE-03

TABLE 10. SPECIES PREDICTED BY COMPUTATION BUT NOT DETECTED BY CHEMICAL EXPERIMENTS^a

Component ^b	Formula	Typical Mole Fraction Predicted	Pressure Used for Calculation, psi	Propellant
Hydrogen	H ₂	0.26 E-00	14.7	N-5
Carbon, monatomic	С	0.97 E-17	10,000	WC846
Water	H ₂ 0	0.94 E-01	14.7	N-5
Nitroyen	N ₂	0.11 E-00	14.7	N-5
Oxygen	02	0.15 E-11	10,000	WC846
Nitric oxide	NO	0.36 E-08	10,000	WC846
Methylidyne	СН	0.19 E-14	10,000	WC846
Methylene	CH ₂	0.81 E-08	10,000	WC846
Methyl	CH3	0.19 E-05	10,000	WC846
Imidogen	NH	0.18 E-09	10,000	WC846
Amidogen	NH ₂	0.62 E-07	10,000	WC846
Cyanogen	C2H2	0.13 E-09	10,000	WC846
Hydroxyl	ОН	0.22 E-06	10,000	WC846

^aSpecific examples of typical results given for illustration.

TABLE 11. COMPONENTS REPORTED BY CHEMICAL ANALYSIS BUT NOT PREDICTED IN THE COMPUTATION RESULTS

Component	Typical Mole Fraction	Weapon
Cyanogen	0.50 E-03	All
Carbonyl sulfide	0.10 E-03	Both machine guns
Benzene	0.10 E-04	7.62 mm machine gun
Acetaldehyde	0.50 E-03	Caliber .50 machine gun
Hydrogen chloride	Trace	Rocket plume only
Sulfur dioxide	Trace	Rocket plume only
Copper and lead	50 mg/m³ of air	Both machine guns

^bGaseous state.

TABLE 12. FROJECT NEST DATA, CALIBER .50 WICHINE GUN

2	8	LOC Inst	Semple			දි	S	ŧ	Z	£	Z	Ş	Š	7.	‡		CHICHO	ş	S		3		<u>ئ</u>	_5
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TABLE 13. PROJECT NEST DATA, 7.62m WICHINE GUN

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TABLE 14. PROJECT MEST DATA, 2,75 in. ROCKET (FFAR)

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TABLE 15. CHEMICAL SPECIES USED IN THEORETICAL PERFORMANCE CALCULATIONS

Formula	Species	Formula	Species
С	Carbon, monatomic	H ₂	Hydrogen, diatomic (reference state, gaseous)
C ₂	Carbon, diatomic	H ₂ 0	Water
Сз	Carbon, trimeric	HCN	Hydrogen cyanide
СН	Methylidyne	N	Nitrogen, diatomic
CH ₂	Methylene	N_2	Nitrogen, diatomic
СНз	Methyl	NH	Imidogen
CH4	Methane	NH_2	Amidogen
C_2H_2	Acetylene	NH ₃	Ammonia
C2N2	Cyanogen	NO	Nitric oxide
CO	Carbon monoxide	NO_2	Nitrogen dioxide
CO ₂	Carbon dioxide	0	Oxygen, monatomic
C(S)	Carbon (reference state, graphite)	02	Oxygen, diatomic
Н	Hydrogen, monatomic	ОН	Hydroxyl

4. Analysis of Exhaust Gases from the XM-19 Rifle--An Application of Gas Chromatography/Mass Spectrometry

USA Ballistic Research Laboratories, Aberdeen Proving Grounds ROT E Project No. IJ563607D013, 1973. AD 910937.

The above chemical analytical technique was used to determine the composition of gases resulting from firing the XM-19 rifle with the XM-645 flechette round and the results compared with theoretical performance calculations. The experimental sampling arrangement was similar to that used in the previous study with the rifle mounted in a suitable stand. Gas samples were withdrawn from the enclosure area, after firing a number of rounds, in evacuated glass flasks. In addition, some cryogenic trapping procedures were also used. No attempt to collect aerosol samples was made.

Theoretical product calculations were made with a code named Blake--a modification of the Tiger code developed by SRI for BRL. The modifications were made by Dr. E. Freedman of BRL. The chemical species included in the calculation are given in Table 16 and the propellant composition in Table 17. Typical results from the program are presented in Table 18.

TABLE 16. LIST OF CHEMICAL SPECIES INCLUDED IN THERMODYNAMIC CALCULATIONS^a

CO	S
H ₂ 0	0 ₂
H ₂	C ₂ H ₂
N ₂	C ₂ H ₄
CO_2	CNCN
КОН	ОН
H ₂ S	CN
NH ₃	HS
HCN	S0
K	CH ₃
CH ₂ 0	Н
COS	K0
NO	0
SO ₂	N
CH4	C

^aAll species in gaseous state, except C, a solid.

TABLE 17. NOMINAL COMPOSITION OF X-2374.13 PROPELLANT AND PISTON PRIMER

Propellant	Weight	Component	Wt%	% of Total Weight ^a
x-2374.13	1.3 g	Nitrocellulose	85.0	82.6
		Nitroglycerine	9.4	9.1
		Diphenylamine	0.9	.88
		Dinitrotoluene	0.7	.6 8
		Dibutyl phthalate	2.8	2.7
		Potassium sulfate	0.5	.48
		Moisture and volatiles	0.7	.6 8
Piston Primer	0.037 g	Lead styphnate	37 ±5	1.02
	-	Tetracene	4 ±1	.11
		Barium nitrate	32 ±5	.89
		Antimony sulfide	15 ±2	.41
		Aluminum powder	7 ±1	.19
		PETN	5 ±1	.14
Tota l b	1.337 g			100%

^aPercent component weight of total charge; propellant and primer.

 $^{^{\}mathrm{b}}\mathrm{Total}$ weight of propellant and primer.

TABLE 18. COMPARISON OF EXPERIMENTAL AND CALCULATED PRODUCT CONCENTRATIONS FOR X-2374.13 PROPELLANT^a

Species	Calculated	Measured	Species	Calculated	Measured
CO	1000	(1000)	C ₂ H ₂	2.86x10 ⁻⁵	>1 ^b
H ₂ 0	476	d nm ^C	C2H4	3.80x10 ⁻⁵	
H ₂	389		CNCN	1.57×10 ⁻⁸	.25
N ₂	289	d nm	ОН	5.97x10 ⁻⁴	
CO ₂	364	380	CN	1.45×10 ⁻⁸	
KOH	3.34		HS	3.73x10 ⁻³	
H ₂ S	1.65		\$0	8.27x10 ⁻⁵	
NH3	3.66x10 ⁻¹	d nm	CH ₃	2.28x10 ⁻⁴	
HC N	3.69x10 ⁻²	dnm	н	1.01x10 ⁻²	
K	1.97x10 ⁻¹		ко	8.43x10 ⁻⁷	
CH ₂ O	1.98x10 ⁻²		0	1.28x10 ⁻⁸	
COS	1.18x10 ⁻¹	.25	N	3.10x10 ⁻¹⁰	
NO	1.08x10 ⁻⁵	dnm	C3 H4	(NI) ^d	<.1
S0 ₂	3.35x10 ⁻⁴		C3H6	(NI)	.1
CH4	3.56x10 ⁻¹	1	C3 H8	(NI)	<.1
S	8.29x10 ⁻⁶		C ₂ H ₆	(NI)	dnm
02	7.27x10 ⁻⁹	dnm			

 $^{^{\}rm a}$ Values are normalized to CO; [(Concentration of component/concentration of CO) x $10^{\rm 3}$]

 $^{^{\}mbox{\scriptsize b}}\mbox{\scriptsize Measured}$ value includes both $\mbox{\scriptsize C}_2\mbox{\scriptsize H}_2$ and $\mbox{\scriptsize C}_2\mbox{\scriptsize H}_4$.

^CDetected, but did not quantify

 $^{^{\}mathbf{d}}\mathbf{Not}$ included in these calculations.

5. Reduced-Smoke Solid Propellant Combustion Products Analysis-Development of a Micromotor Combustor Technique

U.S. Air Force, Edwards Air Force Base Job Order No. 573010CN, 1976. AD A032152.

A small motor was developed to burn a few grams of the rocket propellant given in Table 19 at pressures from 200-1500 psi with subsequent analysis of nine condensable gases by gas chromatography and mass spectrometry. For the former technique, gas samples of the combustion effluents were collected in evacuated glass flasks or metal cylinders. In the latter technique, a water-cooled probe was used to sample directly into the mass spectrometer from the motor exit nozzle. Typical analytical data are shown in Tables 20 and 21 where the results of theoretical calculations are also given for comparison. No details of the theoretical computations were given.

TABLE 19. ROCKET PROPELLANT COMPOSITION

Ingredient	Wt%
Binder	12.5
Ammonium perchlorate	85.0
Zirconium carbide	0.5
Graphite	1.0
Aluminum oxide	0.5
Ferric fluoride	0.5

TABLE 20. COMBINED ANALYTICAL DATA
[Reduced-Smoke Propellant, Combustion Gas Composition]

Species	Mass Spectral Mean	Gas Chromatographic Mean	Combined Mean	Theoretical Data
H ₂	20.1	20.1	20.1	16.1
N ₂	53.4	21.6	21.6	23.2
CO		31.2	31.2	33.2
CO ₂	26.0	26.9	26.5	27.6
CH4	0.19	0.13	0.16	
C ₂ H ₂	0.15	0.06	0.11	
02	0.23		0.23	0.21
Ratio				
CO/CO ₂			1.177	1.202
N_2/CO_2			0.815	0.841
H_2/CO_2			0.758	0.583

TABLE 21. HIGH PRESSURE COMBUSTION GAS CORRELATION

Species	High, 1500 psi	Average, 350-1000 psi	Theoretical, 500-1500 psi
H ₂	22.0	20.1	16.1
N ₂	20.3	21.6	23.2
CO	33.1	31.2	33.2
CO ₂	24.2	26.5	27.6
CH4	0.16	0.16	
C ₂ H ₂		0.11	
02	0.14	0.23	0.21
Ratio			
CO/CO ₂	1.37	1.18	1.20
N ₂ /CO ₂	0.84	0.82	0.84
H ₂ /CO ₂	0.91	0.76	0.58

6. Summary of Airborne Chlorine and Hydrogen Chloride Gas Measurements for August 10 and September 6, 1977, Voyager Launches at Air Force Eastern Test Range, Florida

NASA Technical Memorandum 78673, 1978.

This program presents the results of an airborne sampling program in the wakes of Titan rockets. Measurements were made from about 2 min after launch to as long as 4-1/2 h after launch. All sampling was at an altitude of 500-1500 m at distances out to 100 km from the launch pad. Maximum observed hydrogen chloride concentrations for both launches was $\approx 25-30$ ppm occurring 2-6 min after launch. Maxima in the chlorine concentration at 40-55 ppb occurred in the same time frame. Details of the analytical techniques were given. In addition, the exhaust product composition from a Titan rocket was given. This is shown in Table 22.

TABLE 22. EXHAUST PRODUCT COMPOSITION

Species	Formula	Mass Fraction Afterburned Plume ^a	Nominal Conc. in Stabilized Ground Cloud ^b
Aluminum oxide	A1 ₂ 0 ₃	30.4	1000-3000 µg/m³
Carbon monoxide	CO	.1	<1 ppm
Hydrogen chloride	HC1	20.4	5-40 ppm
Water vapor	H ₂ 0	31.9	c
Carbon dioxide	CU ₂	48.0	Ambient Values
Chlorine	Cl2	2.3	d
Nitrogen oxide	NO	1.2	200-800 ppb
Others		0.6	c

^aIncludes only that entrained air combusted in afterburning; total mass fraction is greater than 100% as reference mass for calculation is exhaust effluents from the motors.

bRange of nominal concentrations measured in earlier Titan III monitoring programs (Refs. 2-6 of NASA TM-78673).

^CNot measured in monitoring program.

dNot measured in previous monitoring program.

7. Toxicological and Recalcitrant Properties of a Proposed Propellant Ingredient, Triaminoguanidine Nitrate (TAGN) Analysis of the Deflagration By-Products of a TAGN-Based Propellant

U.S. Air Force, Eglin Air Force Base, Florida Report No. AFATL-TR-76-161, 1976. AD A041050.

The propellant formulations listed in Table 23 were subject to combustion in closed bombs at terminal pressures in the range of 11,500 to 31,000 psi, and the combustion products were analyzed by gas chromatography. The results are presented in Table 24.

TABLE 23. FORMULATIONS OF THE VARIOUS PROPELLANTS USED IN THIS STUDY

Propellant	Chemical Composition	% Total*
Hercules' GAU-8	Nitrocellulose (NC)	82.30
Extract	Nitroglycerine (NG)	9.37
	Dibutyl phthalate (DBP)	4.17
	Diphenylamine (DPA)	0.54
	Potassium nitrate (KNO ₃)	0.56
	Hercote C _{5.142} H _{8.75} O _{1.838}	3.06
Rocketdyne's	Nitrocellulose (NC)	19.00
RGP-150	Triaminoguanidine nitrate (TAGN)	45.00
	Cyclotetramethylenetetranitramine (HMX)	30.00
	Isodecyl pelargonate (IDP)	5.00
	Resorcinol	1.00
M-10	Nitrocellulose (NC)	97.40
	Diphenylamine (DPA)	1.00
	Graphite glaze	0.10
	Carbon black	0.50
	Potassium sulfate $(K_2 SO_4)$	1.00
Triple Base	Nitrocellulose (NC)	28.04
•	Nitroglycerine (NG)	20.12
	Ethylcellulose (EC)	1.00
	Potassium sulfate (K ₂ SO ₄)	0.25
	Nitroguanidine (NQ)	50.59
WC870	Nitrocellulose (NC)	80.23
	Nitroglycerine (NG)	9.66
	Diphenylamine (DPA)	1.06
	Potassium nitrate (KNO ₃)	0.50
	Dibutylphthalate (DBP)	7.38
	Potassium sulfate (K ₂ SO ₄)	0.38
	Dinitrotoluene (DNT)	0.52
	Calcium carbonate (ĆaCO ₃)	0.05
	Sodium sulfate (Na ₂ SO ₄)	0.12
	Graphite	0.10

^{*}Among product batches, it is common to have minor variations in constituent percentages.

TABLE 24. PERCENTAGES OF GASES PRODUCED WHEN SELECTED PROPELLANTS
WERE BURNED UNDER HIGH AND LOW PRESSURES

Propellant	Pressure, psi	£	N ₂	02	N20	00	c0 ₂	CH.	C2H4	H ₂ 0
RGP-150	Atm	:	84.0	8.7	:	:	5.8	:	:	1.5
RGP-150	13,000	0.2	42.2	tr	1	40.0	6.4	4.6	ł	9.9
RGP-150	31,000	0.3	41.3	0.1	1	31.4	10.0	12.7	ł	4.2
GAU-8 Extract	Atm	;	43.5	7.4	ļ	5.3	28.9	t	;	14.4
GAU-8 Extract	11,500	0.3	15.3	0.3	1	50.9	14.8	2.3	ł	16.1
GAU-8 Extract	28,000	0.3	12.7	;	1	42.0	20.8	7.1	ł	17.1
M-10	Atm	;	51.0	15.7	1	1.6	22.2	:	;	9.5
M-10	13,000	0.4	16.2	;	;	57.7	20.4	1.3	;	4.0
M-10	30,000	0.2	15.6	1	1	40.9	30.2	3.2	i	6.6
WC870	Atm	ł	9.09	5.1	;	4.0	20.2	í	ł	10.1
WC870	12,000	0.3	16.2	ł	i	9.09	16.3	2.4	1	4.2
WC870	27,000	0.2	16.6	0.3	;	49.0	25.4	4.9	;	3.6
Triple Base	Atm	;	65.9	17.5	t	5.5	4.1	;	2.6	7.4
Triple Base	13,000	tr	37.8	ļ	i	38.7	12.5	2.0	i i	0.6
Triple Base	27,000	tr	35.9	;	;	38.9	14.2	2.1	1	8.9

APPENDIX II

THEORETICAL COMBUSTION PRODUCT CALCULATIONS FOR THE WC844 PROPELLANT ASSUMING EQUILIBRIUM AND FROZEN COMPOSITIONS DURING EXPANSION AT INITIAL PRODUCT PRESSURES OF 20,000, 30,000, 40,000, 50,000, AND 60,000 psi

TABLE 25. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2) [10,000 psi]

DEN SITY 6/CC 0.0 0.0 0.0 0.0		
TEMP DEN DEG K G/O 298-15 0.0 298-15 0.0 298-15 0.0 298-15 0.0 298-15 0.0	0.0	
STATE 11 S 29 S 29 S 29 S 29 S 29 S 29 S 29	REACTANT DENSITY#	EXIT 586.57 1.1601 917.6 4.0767-4 -1320.7 2.1593 2.6.461 -1.08867 2.7198 2.9814 1.1082 565.3 4.361 50.000 4502 1.796 263.3
ENERGY CAL/HOL -164700,000 27900,000 -200000,000 -326300,000	REACTANI	EXIT 198,73 3,4240 1,0794-3 1,0794-3 1,0794-3 2,1593 2,1593 2,7932 2,7932 2,7932 2,7932 2,7932 2,7932 2,7932 2,7932 2,9946 1,1153 1,696 1
WT FRACTION (SEE NOTE) 0.951500 0.004000 0.005000 0.005000	PH1≈ 0.0	EXIT 84.726 8.0313 10.71313 2.2834-3 1. -11.73-2 . 2.1593 -1.03436-1 1.4968 0.9989 1.1682 645.2 3.410 10.000 4502 1.604 240.9
30		EXIT 33.855 20.099 1218.2 1089.3 2.1593 2.1593 2.1593 0.5559 1.2141 707.6 2.876 5.0000 4502 1.483
	EOUIVALENCE RATIO= 1.6846	EXIT 1.3420 507.06 2245.06 2245.0 6.7084-2 -650.0 2.1593 2.1593 1.00040 1.2388 974.0 0.699 1.1000 4502 0.496
10.27200	UI VALENCE	EXIT 1-1238 605-48 2323-7 7-7420-2 -616-9 2-1593 2-
O		EXIT 1.0087 6376.58 2372.2 8.4489-2 -596.3 2.1593 2.1593 1.00046 1.00046 1.2361 1000.0 0.119 5.0000 4502 0.087
N 2.63580 N 1.00000 0 4.00000 0 4.00000	L = 100.0000	EXIT 1.0021 679.03 2375.2 8.4940-2 595.0 2.1593 24.380 -1.00046 1.2360 10.006 0.059 10.000
7.36400 11.00000 14.0000 1.00000 1.00000	PERCENT FUEL =	THROAT 1.7966 378.74 21.22.6 5.3017-2 -701.9 2.1593 24.381 -1.00037 1.2409 947.7 1.000 1.0000 4502
FOR THE CO		CHAMBER 1.0000 680.46 2376.45 2376.45 2.1593 24.380 -1.00046 1.00046 1.2360 1000.8
CHEMICAL C 6.0000 C 1.0000 C 12.0000 C 18.0000 C 18.0000 C 18.0000 C 18.0000	0/F= 0.0	5) (K) 17 10) (K) 16) (K) 17) SEC 17) SEC
FUEL FUEL FUEL FUEL FUEL		PC/P T, DEG K RHO, G/CC H, CAL/G S, CAL/(G) M, MOL WT (DLV/DLP) (OLV/D

of 2) ACCIMING ENIT IDDIIM CONDOCTION NIDING EVDANCION (name 2

TABLE 25.	. THEORETICAL ROCKET	CAL ROCK		RMANCE A	ASSUMING [10,	ING EQUILIB [10,000 psi]	RIUM CO	MPOS IT IO	V DUR ING	PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page [10,000 psi]	2	of 2)
MOLE FRACTIONS	IONS					:						
į	•	,				,	,	,		,		
c(s)	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.01615	0.05233		
CHSO	0.00003	0.00002	0.00002	0.00002	0.00002	0.00002	00000	_	00000	0.0000		
CH.	0.00001	0.00002		0.0000	0.00002	0.00002	0.00270	_	0.01557	0.01304		
8	0.45184	0.44553		0.45175	0.45068	0.44883	0.38563	_	0.30994	0.24382		
cos	0.0000	0.00009		0.00009	0.00009	0.0000	0.00003		0.00004	0.00003		
20 5	0.10986	0.11614	0.10989	0.10995	0.11101	0.11284	0.17613		0.23706	0.26668		
CAC03 (S)	0.0	0.0	0.0	0.0	0.0	0.0	0.00013	0.00045	0.00050	0.00050		
CAD(S)	9700070	0.00044		0.00026	0.00032	0.00038	0.0	0.0	0.0	0.0		
CA02H2	0.00023	0.00005	0.00023	0.00022	0.00017	0.0001	0.0	0.0	0.0	0.0		
CAS(S)	0.0	0.0	0.0	0.0	0.0	0.0	0.00036	0.00004	0•0	0.0		
I	0.00020	0.00007		0.00020	0.00016	0.00012	0.00000	_	0.0	0.0		
HCN	0.00005	0.00003	0.00005	0.00005	0.00004	0-0000	0.0000	0.0000	000000	0.0000		
HCO	0.00001	000000	0.00001	0.00001	0.00001	0.00001	0.0	0.0	0.0	0.0		
HNCO	10000*0	000000		0.00001	0.00001	0.0000	0000000	_	00000-0	0.0		
н2	0.13588	0.14222	0.13590	0.13596	0.13704	0.13890	0.19559		0.20293	0.20386		
н20	0.18956	0.18348		0.18948	0.18848	0.18671	0.12793	0.10882	0.10309	0.10560		
Н25	0.00072	0.000 75		0.00072	0.00072	0.00073	0.00048	0.00079	0.00084	0.00085		
ŽH3	0.00014	0.00011		0.00014	0.00013	0.00012	0.00010		0.00007	0.00004		
۸2	0.10930	16 601 0		0.10930	0.10930	0.10930	0.11005		0.11292	0.11238		
¥ Z	0.00038	0.00039	0.00038	0.00038	0.00038	0.00038	0.0000	0000000	0.0	0.0		
NACN	0.00001	0.00002		0.00001	0.00001	0.00001	000000	000000	0•0	0.0		
N A I	£ 0000°0	0.00002	6,00003	0.00003	0.00003	0.0003	0.0	0.0	0.0	0.0		
NAOH	0.00129	0.00128		0.00129	0.00129	0.00129	00000	00000	0000000	0.0		
NA2C03(S)	0,0	0.0		0.0	0.0	0.0	0.0	0.00088	0.00089	0.00088		
NA2CO3 (L.)	c. 0	0.0		0.0	0.0	0.0	0.00086	0.0	0.0	0.0		
Ŧ	0.00005	0.00001	0.00005	0.00005	0.00004	0.00002	0.0	0.0	0.0	0.0		
SH	0.00003	0.00002		0.00003	F0000.0	0.00002	0.00000	0.0	0.0	0.0		
Sŋ	0.00001	0.00000	0.0000	000000	0.000000	0.0000	0.0	0.0	0.0	0.0		
205	0.00001	0.00000	0,00001	0.00001	0.00001	0.00001	0.0	0.0	0•0	0.0		
T T COA	TOWER SECTIONS OF THE PERSON O	יי אניסטר היי	0000	מיות החטכם	1	MANT PASS BEST PROTECTIONS	1 222 1		23 50-30000000000000000000000000000000000	FOR ALL ASSIGNED CONDITIONS	TONDIT	IONS
AUUIIIONAL	THE CLOCKY	נא אבאנ נט	טבאבט	BUT WHUSE	10E	CNOTION AC	אב ובפס			JA ALL A3310N	100000	

C.2	ప	C A02H2(S)	H2S04(L)	N20	NAOHILI	NA202 (S)	8 (8)	
C S 2	C305	CAOH	H202	N2H4	NADH(S)	NA202(S)	03	
S	£3	CAO	H20(L)	N03	N AO	NAZO	20	
CN2	C 20	CA0(1)	H20(S)	N02	NACN (L)	NA20(L)	0	88
CNN	C2 N2	CA C03 (S)	H0 2	CN	NA CN(S)	NA 20(S)	NA 2504	820
N.	C 28	CA	H NO3	NH2	NACLO	NA20(S)	NA2504(L)	25
£	C2H6	CA(L)	FIND 2	ĭ	NA(S)	NA 2C 2N 2	NA 2 SO4 (S)	£05
CH.2	C 2 H 4	CA(S)	ONH	NCO	K N	NA2C03(S)	NA2504(S)	SN
3	C2H2	CA(S)	CA2	z	N 235	NA2	NA2504(S)	s
Ų	C2H	C.5	CAS04 (S)	H2504	N2034	NA02(S)	NA 202H2	211)

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 26. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2) [20,000 psi]

DENSITY G/CC 0.0 0.0 0.0 0.0		
TEMP DEG K 298-15 298-15 298-15 298-15 298-15 298-15	ITY= 0.0	
STATE 000 S	REACTANT DENSITY=	EXIT 577.89 2.358 9.45.4 9.134.1 2.1028 26.795 1.0892 2.7785 1.1114 571.0 4.327 50.000 4502 1.801 2.66.1
ENERGY CAL/MOL -164700.000 27900.000 -200000.000 -326300.000	REAC	EXIT 194.90 6.9826 1023.4 2.1561-3 -1243.5 2.1028 25.931 -1.09915 2.7326 2.7
HT FRACTION (SEE NOTE) 0.951500 0.004000 0.030000 0.030000	PHI= 0.0	EXIT 83.230 16.351 1103.0 4.5656-351 -1173.5 2.1028 25.271 -1.04356 -1.04356 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 1.1149 2.000 4502 1.604 2.013 2.24.4
3 . F 2		EXIT 33.466 40.666 1241.0 9.8815-3 -1088.9 2.1028 24.744 -1.02076 1.2602 0.6813 1.1997 707.3 2.876 5.0000 4502 1.482 228.3
	RATIO= 1.6846	EXIT 1. 3420 1014.12 2246.8 1. 3416.8 1. 3416.8 2. 1028 24.390 24.390 1. 0040 0. 4243 1. 2388 974.1 0. 699 1. 1000 4502 0. 496 184.1 69.4
0 10.27200	EQUIVAL ENCE	EXIT 1-1238 1210-95 2324-7 1-5483-1 1-516-9 2-1028 24-190 0-4265 1-2373 990-2 0-437 1-5000 4502 0-315 230-9
		EXIT 1.0087 1349.15 2373.3 1.6897-1 2-1028 24.390 -1.00032 1.0042 1.0041 0.4281 1.2362 0.119 5.0000 4502 0.087
N 2.63580 N 1.00000 0 4.00000 0 4.0000	0000°001 =1	EXIT 1.0021 1359.05 2376.3 1.6987-1 -595.0 2.1028 24.350 -1.00083 -1.004282 1.2362 1000.7 0.059 10.000 4502 0.043 1401.8
11.00000 11.00000 14.00000 1.00000 1.00000	PERCENT FUEL=	THROAT 1,7966 757,49 2123.5 1,0603-1 -701.9 2,1028 24.390 -1,00077 1,0043 947.7 1,0000 1,0000 1,0000
POPERUIE OO H I		CHAMBER 1.0000 1360.91 2377.91 1.7016-1 -554.6 2.1028 24.390 -1.00082 1.0041 1000.9
= 20000.0 PSIA CHEMICAL L C 6.00000 L C 1.00000 L C 12.00000 L C 18.00000 L C 18.00000 L C 18.00000	0/F= 0.0	(K))(K))(K) SEC R C/LB
PC = 2 FVEL FVEL FVEL FVEL FVEL FVEL FVEL	-	PC/P P. ATM T. DEG K RHO. G/CC H. CAL/G S. CAL/G) CDLV/DLP)

TABLE 26. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 2 of 2)

MOLE FRACTIONS	NNS										
(3)	•	ć	ć	c c	ć	Ġ	Ġ	•	6113	71030	
CH20	0.0005	0.000	0.00005	0.000	0.00	0.0004	0.000		0.0000	0.0000	
CH16.	70000	60000	4000		2000	2000	0.006.0	00710	0.000	01630	
			0.0000	900000		0.0000	30736	0.0100	124 1000	001000	
00	0.104.0	7474	0.100	60164-0	79064-0		0.00455	12266.0	70000	0.23733	
	000000	0.00000	00000	6000	0.0000	0.0000	0.0000	0.0000	00000	0.0000	
(800300)		70110	6001100		0.01	0.711.0	69000	41117.0	10000	76797	
70101	0.000	*****	0000	7000	0.0003	8 6000					
CADSH2	0.000	10000		0.0000	200000	1.000					
	41000-0	9000	0.00014	41000	21000		0.000				
Z	1000	0.0000		1000	210000	7.000.0	0000				
	0000	000000		0.000,		0000	0-0				
HNCO	0.00002	000000		0.0000	0.000.0	0-0001	000000	000000	000000	0.0000	
7	0.13562	0.14157	0.13565	0.13571	0.13679	0.13865	0.18709	0.18888	0.18840	0.18930	
н20	0.18959	0.18349		0.18951	0.18850	0.18673	0.13140	0,11516	0.11258	0.11574	
н25	0.00073	0.000 76	0.00073	0.00073	4200000	0.00074	0.00082	0.00084	0.00085	0.00085	
NH3	0.00027	0.00022	0.00027	0.00027	0.00026	0.00024	0.00018	0.00014	0.00010	900000	
N2	0.10924	0.10927		0.10924	0.10925	0.10926	0.11083	0.11320	0-11372	0.11308	
NA	0.00028	0.00029	0.00028	0.90028	0.00028	0.00029	0000000	0.0000	0.0	0.0	
NACN	0.00003	0.00003		0.00003	0.00003	0.00003	0000000	0.00000	0•0	0.0	
NAM	0.00003	0,00002	0.00003	0.00003	0.00003	600000	0.0	0.0	0.0	0.0	
NAOH	0.00137	0.00136	0.00137	0.00137	0.00137	0.00136	0000000	0.00000	0000000	0.0	
NA2C33 (S)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00089	0.00089	0,00089	
NA2C34 (L)	0.0	0.0	0.0	0.0	0.0	0.0	0.00087	0.0	0.0	0.0	
н.	0.00004	0.00001	0.00003	0.00003	0.00003	0.00002	0.0	0.0	0.0	0.0	
H.S	0.00002	0.0000	0.0000	20000	20000	00000	0000	00000	0	0-0	

C2	**	C A02H2(S)	H202	N2H¢	NAOH(S)	NA202(S)	٤٥	8.8
CS2	C305	CAOH	H20(L.)	N03	NAO	NA20	02	\$ 20
cs	C3	C AO	H20(S)	N02	N ACN (L)	NA20(L)	0	\$ 2
CN2	C 20	CAU(L)	н02	0.0	N ACN (S.)	NA20(S)	NA2504	5.03
CNN	C2N2	CA CO3 (S)	HN 03	NH 2	NA (L)	NA 20(S)	NA 2504 (L.)	202
CN	C 2N	CA	HN02	IZ	NA(S)	NA2C 2N2	NA2504(S)	SO
CH3	С2н6	(1)	DNH	NC U	c N	NA2CO3(S)	NA2 SN4 (S)	Z,
CH2	C2H4	CA(S)	CA2	z	N205	NA2	NA2504(S)	S
CH	C2H2	CA(S)	CAS04(S)	H2504	4C2N	NA02 (S.)	NA202H2	S(L)
U	C2H	C 2	CAS (S)	H2SU4(L)	N 20	NAUH(L)	NA 202 (S)	5 (\$)

NOTE. WEIGHT FPACTION OF FUEL IN TOTAL FUFLS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 27. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2)
[30,000 pst]

TABLE 27. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 2 of 2) [30,000 psi]

MOLE FRACTIONS	ONS										
C(S) CH2D CH4C CO CO CO CO CACO3(S) CACO3(S) CACO3(S) CACO3(S) CACO3(S) HCO HCO HCO HCO HCO HCO HCO NACN NACN NACN NACN NACN NACN NACN NA	C(S) CH2D CH2D CH2D CH4C CO 0.00003 CD COS	0.00 0.000005 0.000018 0.44534 0.44534 0.00003 0.00004 0.00004 0.00004 0.00004 0.00004 0.00004 0.00004 0.00004 0.00004 0.00004 0.00003		0.00003 0.45156 0.00013 0.00010 0.00010 0.00026 0.000026 0.000026 0.00003 0.1856 0.00003 0.1856 0.00003 0.00003 0.00003 0.00003 0.00003 0.00003	0.000014 0.65050 0.000014 0.000010 0.000010 0.000010 0.000010 0.18648 0.18648 0.18648 0.18648 0.000010 0.00003 0.00003 0.00003 0.00003 0.00003 0.00003	0.00 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.	0.00000 0.00000 0.38288 0.00000 0.17955 0.00000 0.00000 0.18621 0.18630 0.18630 0.18630 0.18630 0.18630 0.18630 0.00000 0.000000 0.00000 0.00000		0.00 0.02422 2081 0.02170 5041 0.2948 0005 0.00005 1343 0.23983 0051 0.00005 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1899 0.11950 1899 0.11950 1899 0.11950 1899 0.11950 0.0 0.0 0.0 0.0	0.00000 0.00000 0.01843 0.00004 0.00004 0.000051 0.00000 0.000000 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039 0.18039	A S I GNED CONDITIONS
C C C C C C C C C C C C C C C C C C C	CH C2H2 C2H2 CASO4(S) CASO4(S) H2SO4 N2O4 NAO2(S) NAO2(S)	CH2 CC2H4 CC2H4 CAISI CA2 N N 205 N N 205 N N 2 0 5 N N N 2 0 5 N N N 2 0 5 N N N N S N N N N N N N N N N N N N N N	E E E E E E E E E	CH3 CCH6 CCH6 CA(L) HNO NNO NA2CO3(S) NA2CO3(S)	C C C C C C C C C C C C C C C C C C C	CNN C2N2 CACO3 (S) HN 2 NH 2 NA 20 (S) NA 20 (S)	CCN N CC2N2 CACO1(S) HN O3 HN C3 NA (L) NA 2O(S) NA 2O(S)	- 70ŭ			C 2 C 4 C A 0 2 H 2 (S) H 2 0 2 N A 2 H 4 N A 2 0 2 (S) O 3 S 8

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 28. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2)
[40,000 psi]

DENSITY 6/CC 0.0 0.0 0.0 0.0		
TEMP DEG K 298.15 298.15 298.15 298.15	1TV = 0.0	
STATE 500 S 000 S 000 S 000 S	REACTANT DENSITY=	EXIT 570-27 4.7729 974-2 1.6520-3 -1328-3 2.0463 2.0463 2.5720 2.5720 1.1147 576-5 4.298 50.000 4502 1.806 2.54-9
ENERGY CAL/HOL -16+700-000 0-0 27900-000 -326300-000	REACI	EXIT 191.46 14.216 105.82 4.3038-3 -1245.9 2.0463 -120969 -1.0969 2.5744 1.1226 613.0 3.809 252.7 238.1
HT FRACTION (SEE NOTE) 0.951500 0.004000 0.007500 0.007500 0.005000 0.005000 0.005000 0.005000 0.005000	PHI= 0.0	EXIT 81.833 33.261 1137.8 9.1215.9 9.1217.6 6 2.0463 2.0463 1.07192 1.07192 1.07192 1.0500 4502 4502 1.0605 7.24.8 2.24.7
#2		EXIT 32.975 82.542 1272.8 1.9764-2 2.0463 2.0463 2.0463 1.4067 0.8152 1.1901 709.7 2.866 5.0000 4502 1.482 1.482 1.482 2.866 2.866
	RATIO= 1.6846	EXIT 1.3418 2028.44 2248.7 2.6835-1 2.0463 2.0463 2.0463 1.000 0.4271 1.2384 973.9 0.699 1.1000 1.1000 1.1000 6.696 1.84.1 1.84.1
0 10.2 7200	EQUIVALENCE R	EXIT 1,1238 2,421.95 2,26.6 3,0959-1 2,0463 2,0463 2,441 1,2469 990.0 0,4287 1,2469 990.0 0,437 1,5000 4,5000 4,502 2,30,9
		EXIT 1,0087 2698.32 2375.23 3.3797-13 2.0463 2.0463 2.0463 1.000191 1.000191 1.2359 999.9 0.119 5.0000 4502 0.087
N 2.63580 N 1.00000 G 4.00000 D 4.00000	- 100.0000	EXIT 1.0021 2716.10 23378.2 3.39778.2 2.0463 2.0463 24.412 -1.00192
11.0000 14.0000 1.0000 1.0000 1.0000	PERCENT FUEL=	THRD AT 1.79 62 1515. 28 2125. 62 2.1208-1 2.0463 2.0463 2.0463 2.0463 1.0000 1.0000 4502 0.690
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		CHAMBER 1.0000 2721.83 2379.2 3.40379.2 2.0463 2.0463 0.4000 0.4000 0.4000 1.2359 1000.7 0.0
PC = 40000.0 PSIA CHEMICAL FUEL C 1.00000 FUEL C 12.00000 FUEL C 18.00000 FUEL C 18.00000 FUEL C 18.00000 FUEL C 18.00000	ŋ/F= 0.0	
PC = 4 FUEL FUEL FUEL FUEL FUEL		PC/P P, ATH T, DEG K RHO, G/CC H, CO, G/CG S, CAL/(G) M, MOL WT (DLV/DLP) (GAMMA (S) SQN VEL.M/ MACH NUMBF AE/AT CSTAR, FT/ CF IVAC LB-SE IVAC LB-SE ISP, LB-SE

2 9 THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 2 [40,000 psi] 83 TABLE

0.50000E-05 FOR ALL ASSIGNED CONDITIONS 0.06423 0.00000 0.02004 0.23017 0.00004 0.26931 0.00000 0.17391 0.12607 0.000086 0.00009 0.0 0.0 0.00000 0.00089 0.0000 0.0 000 000 0.02650 0.00000 0.02966 0.00005 0.00005 0.00000 0.00000 0.17302 0.00006 0.00006 0.00006 0.11463 0.0 0.00000 0.00000 000 0.0 0.00000 0.02377 0.34874 0.00005 0.00005 0.00000 0.00000 0.17312 0.12169 0.00000 0.11466 0.00000 0.00000 0.00090 0.0000 0.0 THAN 0.00 0.01152 0.38152 0.00000 0.00000 0.00000 0.00000 0.13640 0.000082 0.000082 0.000082 0.000082 0.00000 0.00000 0.00088 WERE LESS 0.00027 0.4848 0.00009 0.000 0.00011 0.00014 0.00014 0.18683 0.00017 0.10917 0.00021 0.00021 0.00003 0.0000 0.00001 MOLE FRACTIONS 0.0 0.00024 0.45033 0.00010 0.11157 0.0 0.00032 0.00017 0.00016 0.00002 0.00003 0.13612 0.18861 0.00051 0.10915 0.00021 0.00006 0.00003 0.00141 0.00002 0.00 0.00010 0.00023 0.00023 0.00010 0.00026 0.00010 0.00002 0.00004 0.13504 0.13504 0.13504 0.10914 WHOSE 0.00006 0.00002 0.00141 0.00021 EU1 CONST DER ED 0.00032 0.44517 0.00009 0.11670 0.00004 0.00001 0.00001 0.16124 0.00076 0.00076 0.00076 0.00076 0.00003 0.0 0.0 0.00001 0.00001 MERE PRODUCTS WHICH 0.00 0.0010 0.00023 0.00010 0.1004 0.00023 0.00023 0.00023 0.000023 0.000023 0.000023 0.000023 0.000023 0.000023 0.00004 0.00004 0.00004 0.00004 0.00003 MOLE FRACTIONS ADDITIONAL NA2C33 (S) CO COS CO2 CACO31 S) CAO(S) HC0 HNC0 H2 H20 NACN NAOH S H2S NH3

CAD2H2(S) H2O2 N2H4 NAOH(S) NA2O2 (S) 03 CS2 C302 CA0H H20(L) N03 NA0 NA20 02 S20 CAO H20(S) NO? NACN(L) NA20(L) C N 2 C 20 C A 0 (L) H 0 2 N 0 N A 2 0 (S) N A 2 5 0 4 S 0 3 OX I DANTS CVN C2 N2 CA CO3 (S) HN O3 NN L2 NA (L) NA 20 (S) NA 20 (S) TOTAL NA(S) NA2C2N2 NA2S04(S) OXIDANT CA HN02 NH 9 NA2CO3 (S) NA2SO4 (S) AND CH3 C2H6 CA(L) HNO FUELS NCO N3 TOTAL NA2504 (S) Z CH2 C2H4 CA(S) CA2 N205 FUEL z 5 FRACT10N CH C2M2 CA(S) CASO4(S) H2SO4 NA02 (S) NA20 2H2 N204 5 (1.) 1 GH1 NADH(L) NAZOZ(S) 및 H2S04(L) CASISI NOTE. (5)5 N20 ° 24 C2 C5

z

TABLE 29. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2)
[50,000 psi]

6/CC 6/CC 0.0 0.0 0.0 0.0																			
000000	•																		
TEMP DEG K 298.15 298.15 298.15 298.15 298.15	0.0																		
7E 0 0E 298 298 298 298 298 298	DENS ITY=																		
STATE S S S S		EXIT	568.06	983.7	52-3	-1329.9	2.0282	27.294	.08789	2.5680	2.5052	1.1158	578.2	4.290	000	4503	1 4 5 6 5	766.1	6007
7.40L 20.000 00.000 00.000	REACTANT		20	n	2-0252-3	-13	2	27	-1.0	2.	2.		~	4	Č	`	•	1 7	J
ENERGY CAL/MOL -164700.000 27900.000 -200000 -326300.000	REA(EXIT	190.45	1069.7	13	-1246.9	2.0282	26.411	.09833	2.6354	5065	1.1238	615.2	3.798	000	4 503	1, 70,	26.26	
1 117			6 5	Ŏ	5-3754-3	-12	2•(26	-1.0	2.0	2.	-	9	ě	6		_		; ;
KT FRACTION (SEE NOTE) 0.951500 0.004000 0.007500 0.005000	0.0	EXIT	81.400	1149.7	.1396-2	-1175.1	2, 0282	25.122	.05417	1.7432	1.2097	1.1627	657.3	1.353	900	4503	1,606	242.0	
KT FRACTIO (SEE NOTE) 0.951500 0.004000 0.030000 0.005000	= 1 Hd		18		1,13	-11	2.	25	-1.0	-	-	-	9	m	2		_	7	•
¥	•	EXIT	32.810	1284.6	2-20	-1088.9	2,0282	25.108	. 03690	1.4498	0.8520	1.1881	710.9	2.861	2,000	4503	1.482	228.7	
	1.6846		32	12	2-4702-2	01-	2.	25.	-1.0	-	~ •	=	≂	2			_		11
	0= 1.	EXIT	1.3418	2249.9	45-1	-646.9	2,0282	24.423	•00264	1.0141	0.4292	1.2381	973.8	669.0	1000	4503	965-0	184.1	
	RAT10=		753	22	3,3545-1	9-	%	54.	-1.00	:		-	6	ö	3		0	_	•
0	ENCE	EXIT	1,1238	2327.7	8713-1	6.919-	2.0282	24.423	•00260	1.0129	0.4305	1.2366	6.686	0.437	2000	4503	0.315	230.9	
10.27200	EOUI VALENCE	•	302	23	3.87	9-	2•1	5%	-1.0	Ξ	ò	-	6	ŏ			0		, `
0	9	EXIT	1.0087	2376.3	1-6+	-59693	2.0282	24.424	260	1.0124	0.4315	1.2356	1.666	0.119	2.0000	4503	0.087	705.9	
00000	00		347	23	4.2249-1	- 5	2•(24.	-1.00260	-	•	=	ŏ	Ö	2.0	•	Ö	7	•
2.63580 1.00000 4.00000 3.00000	000.00	EXIT	120021	79.3	74-1	95.0	2.0282			1.0124	0.4316	1,2355	00	020	000	4503	043		•
Z ZC:00			939	23	4.54	Š	7•(24.	-1.00	<u>.</u>	· •	-	ĕ	ċ	01	•	Ċ	140	
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	PERCENT FUEL =	THROAT	1894.40	2127.0	11-1	- 701.8	28 70 • 2			1.0170	0.4786	1 • 2399	947.5	2000	0000	4503	0.690	174.5	7 70
HULA H 7.36400 H 11.00000 H 14.00000 S 1.00000	ERCEN	Ξ -	189	2.1	2.6511-1	-	2.	56	-1.00285		.	-	Φ,	-	-	•	0	_	
DRAU H H N O	<u>a</u>	CHAMBER	3402.28	2380.2	45-1	-594.6	7970•7	24.424	0560	1.0124	9164-0	1.2355	1000.5	0.0					
CHEMICAL FORMULA 6.00000 H 7 1.00000 12.00000 H 11 18.00000 H 14 A Z.00000 S 1 A 1.00000 C 1	6	CHA	340	23	4.2545-1	5,	•	24	-1.00260	: (.	• •	2 '	•					
CHEMICAL C 6.00000 C 1.00000 C 12.00000 C 18.00000 NA 2.00000	0.0					2	2			3			ر د	Y		SEC		7.18	d :/:
	0/F=			¥	<u>ي</u> د د	M. CAL/G		1			2	3	SUM VELOM/SEC	MACH AUMBER		CSTAR, FT/SEC		IVAC LB-SEC/LB	A-CF
FUEL FUEL FUEL FUEL FUEL		97.78	P. ATM	T. DEG K	RHD. G/CC	M. CALVO	י	M. MOL WT	1010/01/91 T			CATER CA)	ב ב	AE/AT	STAR.		AC L	ISP. 18-SEC/18
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~		٥	•	-	₹ :	Ē۷	ñ	2	_ ;		ີ ເ	3 8	ร รี	Ě	AE	ప	u U	_	_

2 9 THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 2 [50,000 psi] TABLE 29.

MOLE FRACTIONS WERE LESS THAN 0.50000E-05 FOR ALL ASSIGNED CONDITIONS 0.00000 0.02134 0.22753 0.00004 0.27008 0.0000 0.16880 0.12941 0.00086 0.00010 0.00000 0.00000 0.0 0.0 C S 2 C 3 0 2 C A 0 H H 2 0 (L) N D 3 N A 2 0 0 2 S 2 0 0.02496 0.29396 0.00005 0.24204 0.02834 0.00000 0.0 0.16793 0.12535 0.00085 0.11494 0.00000 0.00000 0.00000 0.00016 000 0.0 0.34734 0.00006 0.21718 0.00051 0.0 0.00000 0.00000 0.00000 1000000 0.00000 0.16781 0.12379 0.000085 0.00024 0.000000 0.00000 0.0000 0.0 0.38028 0.00006 0.18274 0.00050 0.00000 0.17025 0.13817 0.00082 0.00000 0.00000 0.11238 0.0000 0.00088 0.01357 0.00001 0.0 000 CN 2 C2 0 CA O(L) 0.00000 0.00000 0.00001 0.00001 0.00001 0.00001 0.00001 0.00001 0.00001 0.00001 0.00001 0.00001 0.00001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 CNN C2N2 CAC03(S) HN03 NH22 NA4(L) NA2(L) NA2(S) 0.45012 0.00010 0.11183 0.00031 0.00017 0.00000 0.00002 0.00002 0.10911 0.10911 0.00019 0.00019 0.0 0.00011 0.00000 0.00002 0.0 BUT WHOSE 0.45118 0.00010 0.11079 0.0 0.00026 0.00023 0.00009 0.0 0.00012 0.00001 0.00036 0.00022 0.13463 0.18968 0.00074 0.10909 0.00008 0.00002 0.00066 0.0 0.00012 0.00013 0.00013 0.00013 0.00002 0.00002 0.00002 0.00002 0.00004 0.10909 0.00018 0.000018 0.000018 0.000018 0.0000142 0.000018 ADDITIONAL PRODUCTS WHICH WERE CONSIDERED 0.00014 0.00001 0.00002 0.14078 0.18371 0.00076 0.10919 0.00000 0.00049 0.44495 0.00009 0.11698 0.00003 0.00044 0.0 0.00009 0.00003 CH2 C 2H6 C A (L) HNO 0**.** 000 01 0.0 0.0002 0.00004 0.13455 0.00014 0.00014 0.00018 0.00008 0.00008 0.00001 0.00035 0.45127 0.00010 0.11071 0.00025 0.0 0.0 C 2H4 CA(S) MOLE FRACTIONS NAUH NA2CO3 (S) NA2CO3 (L) OH CO COS CO2 CACO31S) C2H2 CA(S) CASD4(S) H2SD4 CA02H2 CAO (S) HCO HCO H2 H20 H2 S NACN ZUI CIT

FUEL IN TOTAL FUELS AND OF DXIDANT IN TOTAL DXIDANTS WEIGHT FRACTION OF

CAS(S) H2504(L) N20 NAOH(L) NA202(S) S(S)

H2D2 N2H4 NADH(S) NA2Q2(S) O3

NACN(L) NA20(L) O

ND CN(S) NA 20(S) NA 2504 SO 3

NA(S) NA2C2N2 NA2SO4(S) SO

NA2C03(S) NA2S04(S)

NA2504 (S)

NA021 S 1 NA202H2

S(L)

N205

N204

HN02

C AO H 20(S) NO2

CA02H2(5)

TABLE 30. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2) [60,000 psi]

DENSITY 6/CC 0.0 0.0 0.0 0.0		
TEMP DE C 298.15 0.2988.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.20888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.208888.15 0.2088888.15 0.2088888.15 0.2088888888888888888888888888888888888	Y= 0.0	
STATE S S S S S	REACTANT DENSITY=	EXIT 566.56 7.2062 2.4211-3 -13311-3 -13311-3 -13311-3 2.0134 2.50134 1.1166 579.6 6.284 1.808 1.808
ENERGY CAL/HOL -164700.000 27900.000 -200000.000 -326300.000	REACT	EXIT 189-73 21-519 107-73 2-6-4435-3 2-6-1247-8 2-6-134 2-6-136 2-6-13
MT FRACTION (SEE NOTE) 0.951500 0.004000 0.004000 0.030000 0.005000	PHI= 0.0	EXIT 81.092 50.347 11.3664-2 -11.75-7 2.0134 25.821 -1.05577 1.2186 1.1626 658.8 3.347 1.600 1.600 1.600
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3		EXIT 32.689 124.90 1294.6 2.9656-2 -1089.0 2.0134 2.0134 1.03984 1.03984 1.1868 712.0 2.857 5.0000 4504 1.482
	EQUIVALENCE RATIO= 1.6846	EXIT 1. 3412 3044.06 2251.3 4.0251.3 4.049.9 2.0134 24.436 -1.00346 1.4118 0.4118 0.699 1.1000 4504 0.495
0 10.27200	II V AL ENCE	EXIT 1-1237 3633-43 2329-0 4-6460-1 2-0134 2-0134 2-0134 1-2363 989-8 0-437 0-437 0-437 0-437
		EXIT 1.0087 4047.48 2377.5 5.070-1 2.0134 2.0134 1.00337 1.2353 999.6 0.119 5.0000 4504 0.087
N 2.63580 N 1.00000 O 4.00000 D 4.00000	- 100.0000	EXIT 1,0021 4074,16 2380,4 5,090,01 2,0134 24,437 -1,00337 -1,00337 -1,000,2 0,059 10,000 4504 0,059 1,000,2
MULA H 7.36400 H 11.00000 H 14.00000 S 1.00000 C 1.00000	PERCENT FUEL=	THRO AT 1.7916 2278.77 2130.4 3.1864-1 -701.4 2.0134 24.443 -1.00529 -1.00529 -1.00538 1.2340 945.6 1.0000 4504
FORMU O H O S		CHAMBER 1.0000 4082.74 2381.4 5.1057-1 2.0134 2.0134 1.00337-1 1.0163 0.4335 1.2352 1000.4
PC = 60000.0 PSIA CHEMICAL FUEL C 1.00000 FUEL C 12.00000 FUEL C 18.00000 FUEL C 18.00000 FUEL C 18.00000	0/F= 0.0	. 1 (K.) P 6.1(K.) 7.SEC F 7.SEC
PC = 6 FUEL FUEL FUEL FUEL FUEL FUEL		PC/P T, DEG K RHO, G/CC H, CoL/G) S, CaL/G) M, MDL WT (DLV/OLP) (D

2 of THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page ස් TABLE

C 2H C 5 C A 5 (5) H 2 5 0 4 (L) N 2 0 4 N A 2 0 5 (L) N A 2 0 2 H 2 S (L) ASSIGNED CONDITIONS C 2 C 4 C A D 2 H 2 D 2 N 2 D 2 N A 2 D 2 (S) N A 2 D 2 (S) S (S) 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.06796 0.00000 0.0 0.16458 0.02243 0.22525 0.00004 0.27080 0.0000 0.00011 0.00086 0.0000 ALL 0.0 CS2 C302 CA0H H20(L) N2H4 NA0H(S) NA202(S) 03 FOR 0.02617 0.29160 0.000051 0.000051 0.000000 0.000000 0.12791 0.00000 0.000000 0.011520 0.000000 0.000000 0.02991 0.00000 0.0 0.50000E-05 0.00000 0.00000 0.02815 0.02806 0.21872 0.00000 0.00000 0.16339 0.00000 0.1567 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 CS C3 CAO H2O(S) NU3 NAO NA2O 02 S2O THAN 0.0 0.00001 0.01535 0.37911 0.00006 0.00001 0.00001 0.00000 0.00000 0.16633 0.1863 0.0 0.00036 0.00000 0.00000 0.0 0.00000 LESS CN 2 C2 0 CAO(L) HO 2 NO 2 NA CN (L) NA 20(L) 0 FRACTIONS WERE [60,000 psi] 0.0 0.00011 0.00001 0.00008 0.000008 0.00003 0.00001 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00142 0.00001 C NN C 2N2 C ACO 3 (S) H NO 3 0.0 0.00013 0.000013 0.000053 0.00010 0.000011 0.000024 0.000024 0.000024 0.000024 0.000024 0.000024 0.000024 0.00075 0.00000 0.00000 0.00000 0.000003 0.000002 0.000002 0.000002 NACN(S) NA2D(S) NA2SO4 MOLE 0 MHOSE 0.00015 0.00015 0.00001 0.00001 0.00002 0.00002 0.00002 0.00002 0.00002 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 0.00007 NACL) NACO(S) NACSO4(L) SOC BUT CA HNO? C SN 0.0 0.00015 0.00050 0.45101 0.00050 0.00023 0.000023 0.000023 0.000023 0.000023 0.000023 0.00003 0.00003 0.00003 0.00003 0.00003 0.00003 0.00003 0.00003 0.00003 0.00003 Ĭ CONSIDERFO NA(S) NA2C 2N2 NA2 SO4 (S) SO 0.00009 0.00009 0.000069 0.000017 0.000016 0.000016 0.000016 0.000016 0.000016 0.000016 0.000016 0.000018 0.000018 0.000018 0.000018 0.000018 0.000018 0.000018 0.000018 CH2 C2H6 CA(L) HNO NCO WERE F ICH 0.0 0.00015 0.00050 0.45103 0.00010 0.00023 0.00023 0.00003 0.00003 0.10905 0.10905 0.10905 0.10905 0.00017 0.00017 0.00142 0.0 0.0 0.00002 0.00001 N3 NA2CO3 (S) NA2SO4 (S) PRODUCTS CH C2H4 CA(S) CA2 z MOLE FRACTIONS ADDITIONAL NA2C03 (S) NA2C03 (L) NA2 NA2 504 (S) C(S) CH20 CH3 CH4 CO CO COS COS CACO3(S) CACO3(S) HCO HCO HNCO N2 NA NACN \$ 2 2

TABLE 31. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2)
[10,000 pst]

DENSITY G/CC 0.0 0.0 0.0 0.0		
	0.0	
TEMP DEG K 298.15 298.15 298.15 298.15 298.15		
57 TAT	T DENS	EXIT 937.99 0.7254 519.8 4.1470-4 -1299.1 2.1593 2.4593 1.3426 487.8 46977 50.000 4493 1.773 2.55.0
00000	REACTANT DENSITY=	4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4
ENERGY CAL/MG -164700 27900 -200000 -326300	æ	EXIT 259.84 2.6188 715.5 11.0874-3 -1234.9 2.1593 2.1593 2.63362 1.3200 5.67.5 4.079 4.493 1.699 246.8
MT FRACTION (SEE NOTE) 0.951500 0.007500 0.007500 0.007500 0.000000 0.005000 0.005000 0.005000	PH I = 0.0	EXIT 97.734 6.9623 902.2 2.2929-3 -1170.7 2.1593 2.1593 1.3016 632.8 3.470 10.000 4493 1.603 238.2
E S		EXIT 36.112 18.843 1130-4 4.9527-3 -1088-5 2.1593 2.1593 2.1593 2.1593 2.889 703-7 2.889 5.0000 4493 1.485 226.7
	EQUIVALENCE RATIO= 1.6846	EXIT 1.3436 506.46 2242.2 6.7110-2 -650.2 2.1593 2.4.380 0.4133 1.2457 976.0 0.699 1.1000 4493 0.498 183.9
0 10.2 7200	IV AL ENCE	EXIT 1.1244 605.19 2322.2 7.7432-2 -617-0 2.1593 24.380 0.4151 1.2443 992.7 0.437 1.5000 4493 0.317 230.5
_		EXIT 1.0088 674.55 2372.1 8.4489-2 -596.3 2.1593 2.4593 1003.0 0.119 5.0000 4493 0.087
N 2.63580 N 1.00000 0 4.00000 0 4.00000	.= 100.0000	EXIT 1.0021 679-02 2375-2 8.4939-2 -595-0 2.1593 24.380 0.4163 1122435 11003-6 0.059 110-000 4493 0.063
HULA H 7.36400 H 11.00000 H 14.00000 S 1.00000	PERCENT FUEL=	THROAT 1.8011 377.81 2115.8 5.3054-2 -702.2 2.1593 24.380 0.4101 1.2480 949.0 1.0000 1.0000 4493 0.653
, and the second	1 <u>3</u> 4	CHAMBER 1.0000 680.46 2376.2 8.5083-2 2.1593 24.380 0.4163 1003.8
CHEMICAL C 6.00000 C 1.00000 C 12.00000 C 18.00000 NA 2.00000	0.0	~ 60 #
PC = 10000.0 PSIA CHEMICAL FUEL C 6.0000 FUEL C 12.0000 FUEL C 18.0000 FUEL C 18.0000 FUEL C 18.0000	0/F =	PC/P T, DEG K H, CAL/G S, CAL/G)(K) M, MOL WT CP, CAL/G)(K) GAMMA (S) SGN VEL.M/SEC MACH NUMBER AE/AT CSTAR, FT/SEC CF IVAC LB-SEC/LB
70 = 1 FUEL FUEL FUEL FUEL FUEL FUEL FUEL		PC/P P. ATM T. DEG K RHO. G/CC H. CAL/G) S. CAL/G) GAMMA (S) SQN VEL.M/S MACH NUMBER AE/AT CSTAR, FT/S CF

TABLE 31. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2) [10,000 psi]

MOLE FRACTIONS

	NDI T IONS	C S2	C 3 0 2	CA0	H20(S)	N02	NACN(L)	NA20(S)	NA2504(L)	25
0009 020 588 930 1129	FOR ALL ASSIGNED CONDITIONS	cs	C	CADIL	Н02	OX	NACN(S)	NA2C2N2	NA2504(S)	S 03
0.00009 0.00020 0.13588 0.10930 0.00129	0E-05 FOR ALL	CN2	C20	CAC03(S)	HN03	NH2	NACLO	NA2C03(L)	4A2S04(S)	NS.
C C C C C C C C C C C C C C C C C C C	THAN 0.50000E-05	CNN	C 2N2	C ACO 3(S)	HN02	I,	NA(S)	NA 2C 03 (S)	NA2504(S)	S
0.45184 0.00023 0.00014 0.00014 0.0003	MOLE FRACTIONS WERE LESS THAN					NC O			NA 202H2	
C0 C402H2 HNCO NH3 NAH S0		С Н 3	C 2H6	CA(L)	CA2	z	N205	NA2	NA202(S)	\$(\$)
0.00001 0.00026 0.00001 0.00072 9.00001 0.00003	DERED PUT WHOSE					H2 S04				
CH4 CAO(S) HCO H2S NACN	WERE CONST	СН	C2 H2	CA(S)	CAS(S)	H2 S04(L)	N 20	NAOH(L)	NA 20	02
0.00003 0.10986 0.00005 0.18956 0.00038	ADDITIONAL PRODUCTS WHICH WERE CUNSIDERED	U	C2H	C 5	CA02H2(S)	H202	N2H4	NAOH (S)	NA20(L)	0 S8
CH2D CG2 HCN H20 NA	ADDIT I ONAL	C(S)	73	*5	CAOH	H20(L)	NO3	NAO	NA20(S)	NA2504 S20

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 32. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2) [20,000 pst]

CAL/MOL -164700.000 S 298.15 0.0 S 298.15 -27900.000 S 298.15 -287900.000 S 298.15 -287900.000 S 298.15 -287900.000 S 298.15 -326900.000 S 298.15 -287900.000 S 298.15 EXIT EXIT EXIT 259.65 2.1745-3 8.2921-4 -1235.1 -1299.3 2.1028 2.1028 2.1028 2.1028 2.1028 1.3423 5.1028 1.3423 5.1028 1.3423 5.1028 2.1028 2.000 S0.000 4.493 4.976 2.000 S0.000 4.493 1.773 2.46.8 255.1	PC = 20000.0 PSIA	4						3	2011				
HILLONGOO HILLONGOO N 1.00000 N 1.00000 S 298.15	- 60 · 6	AL FORMI	ULA 7.36400			10.27200			EE NOTE)	•	2 V S	DEG K 298.15	6/CC 0.0
CHAMBER THROAT EXIT EXIT EXIT EXIT EXIT EXIT EXIT EXI	2.00				0000				0.007500 0.030000 0.05000	27 900 .0 27 900 .0 -200 000 .0 -326 900 .0		298-15 298-15 298-15 298-15	
CHAMBER THROAT EXIT EXIT EXIT EXIT EXIT EXIT EXIT EXI	0.0		PERCENT FUL			U I V AL EN CE	RAT10= 1		0.0 =1H	REACT	ANT DENSI	;	
1.000		CHAMBER	•	•			EXIT	EXIT	EXIT	EXIT	EXIT		
2377.3 2117.0 2376.3 2373.2 2323.3 2243.3 1131.5 903.2 716.5 716.5 1.7016-1 1.0610-1 1.6987-1 1.5485-1 1.3421-1 9.9040-3 4.5851-3 2.1745-3 8594.6 -702.2 -594.0 -596.3 -617.0 -650.2 -1088.6 -1170.8 -1235.1 -54.90 24.3		1360.91		- =	. =		1012,92	36-097	97.680	259.65 5.2413	937.13		
1.016-1 1.0610-1 1.6987-1 1.5485-1 1.3421-1 9.9040-3 4.5851-3 2.1745-3 8. -594.6 -702.2 -595.0 -596.3 -617.0 -650.2 -1088.6 -1170.8 -1235.1 - 2.1028 2.1028 2.1028 2.1028 2.1028 2.1028 2.1028 2.1028 2.1028 -1235.1 - 24.390 24.390 24.390 24.390 24.390 24.390 24.390 24.390 24.390 0.4163 0.4163 0.4167 0.4162 0.4152 0.4133 0.3680 0.3519 0.3563 1.2433 1.2433 1.2432 1.2432 1.2432 1.2433 1.2442 1.2442 1.2455 1.2844 1.3013 1.3198 1.003.8 949.0 1003.6 1002.9 992.6 975.9 703.8 633.0 567.7 0.0 1.000 1.0000 10.000 1.5000 1.1000 5.0000 1.5000 10.000 20.000 44.93 44.93 44.93 44.93 44.93 44.93 44.93 44.93 44.93 44.93 44.93 44.93 44.93 44.93 1.243 1.243 1.243 1.243 1.203.8 1.2		2377,3		2376.3			2243,3	1131.5	903.2	716.5	5 20.6		
24.390 24.300 24.390 24		1-910/-1	:	1-6987-1	:	-	-	9.9040-3		æ	.2921-4		
24.390 24.390 24.390 24.390 24.390 24.390 24.390 24.390 24.390 24.390 24.390	÷	2.1028		2-1028				2.1028	2, 1028		-1299.3 2.1028		
0.4163 0.4102 0.4164 0.4162 0.4152 0.4133 0.3680 0.3519 0.3363 1.2433 1.2479 1.2433 1.2442 1.2442 1.2455 1.2844 1.3013 1.3198 1.0003.8 949.0 10.03.6 1002.9 992.6 975.9 703.8 633.0 567.7 0.00 1.0000 0.059 0.119 0.437 0.699 2.889 3.469 4.078 1.0000 10.0000 5.0000 1.5000 1.1000 5.0000 10.000 20.000 4493 4493 4493 4493 4493 4493 4493 1.4493 0.043 0.043 0.087 0.316 0.498 1.485 1.603 1.609 1.14.3 1399.6 704.3 230.5 183.9 226.7 238.2 246.8 96.8 6.0 12.2 44.2 69.5 207.3 223.9 236.1		24.390		24.390				24.390	24.390	24.390	24,390		
1003.8 949.0 10.03.6 10.02.9 992.6 975.9 703.8 633.0 567.7 0.003.8 1.000 10.003.6 10.02.9 992.6 975.9 703.8 633.0 567.7 0.003.8 1.000 10.000 10.000 1.0000 1.5000 1.5000 1.1000 5.0000 10.000 20.000 4493 4493 4493 4493 4493 4493 4493 1.74.3 1399.6 704.3 230.5 183.9 226.7 238.2 246.8 8 6.0 12.2 44.2 69.5 207.3 223.9 236.1	£	0.4163		0.4167			_	0.3680	0.3519	0.3363	0.3195		
1.000 10.000 0.059 0.119 0.437 0.699 2.889 3.469 4.078 1.0000 10.000 5.0000 1.5000 1.1000 5.0000 10.000 20.000 4493 4493 4493 4493 4493 4493 4493 0.693 0.087 0.316 0.498 1.485 1.603 1.690 174.3 1399.6 704.3 230.5 183.9 226.7 238.2 246.8 8 6.0 12.2 44.2 69.5 207.3 223.9 236.1	Ü.	1003-8		1003.6		-	1.2455	1.2844	1.3013	1,3198	1.3423		
1.0000 10.000 1.5000 1.5000 1.1000 5.0000 10.000 20.000 4493 4493 4493 4493 4493 4493 4493 4		0.0		0.059			669.0	2.889	3.469	4.078	1.88.4		
4497 4497 4497 4497 4497 4493 4493 4493			1.0000	10.000			1.1000	5.0000	10.000	20.000	20,000		
0.693 0.043 0.087 0.316 0.498 1.485 1.603 1.690 1 174.3 1399.6 704.3 230.5 183.9 226.7 238.2 246.8 2 96.8 6.0 12.2 44.2 69.5 207.3 223.9 236.1 2	ບູ		6677	6655			E 644	4493	4493	1699	1099		
174.3 1399.6 704.3 230.5 183.9 226.7 238.2 246.8 96.8 6.0 12.2 44.2 69.5 207.3 223.9 236.1			0.693	0.043	•		0.498	1.485	1.603	1-690	1.773		
96.8 6.0 12.2 44.2 69.5 207.3 223.9 236.1	٦, B		174.3	1399.6	7		183.9	226.7	238.2	246.8	255.1		
	/LB		8.96	0.9			69.5	207.3	223.9	236.1	247.6		

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2) [20,000 psi] TABLE 32.

						T 10NS	C S 2	C 305	CAO	H20(S)	N02	NACNILI	NA20(S)	NA2504(L)	202	
	90	62	54	37		0.50000E-05 FOR ALL ASSIGNED CONDITIONS	cs	S	CAD(L)	70Н	2	NACN(S)	NA2C2N2	NA2S04(S)	20	
	0.00009	0,135	0.10	100.0		16-05 FOR ALL	CN2	020	CAC03(S)	HNO3	NH2	NACLO	NA2C03(L)	NA2S04(S)	NS	
	503 F					THAN 0.50000				HN02						
	0.45178	0.00002	0.00027	0,00003		NS WERE LESS	S	CSN	۲۷	HNO	NC O	K3	NA 2C03 (S)	NA 202H2	S(L)	
	C0 C402H2	HNCO	N:3	NAH		MOLE FRACTIONS WERE LESS THAN				CA2					\$(\$)	
	0.00006	0,00001	0.00073	0.00003	0.00002	JERED BUT WHOSE	CH2	C2H4	CA(S)	CA SO4(S)	H2S04	N204	NA02(S)	NA202(S)	03	SB
	CH4	HCOH	H2S	NACN	¥	H WERE CONSID	Ŧ	C 2H2	CA(S)	CAS(S)	HZ S04(L)	N20	NAOH(L)	NA20	05	\$20
SNO	0.00005	000000	0.18959	0.00028	0.00004	ADDITIONAL PRODUCTS WHICH WERE CONSIDERED	v	C2H	2	CAD 2 H2 (S)	Н202	N 2H4	NAOH (S.)	NA20(L)	0	25
MOLE FRACTIONS	CH20	S	H20	A Z	H	ADDIT IGNAL	C(S)	2 5	3	CAOH	H20(L)	KON	NAO	NA20(S)	NA2504	203

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

2 THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of [30,000 psi] 8 TABLE

0.0 0.0 0.0 0.0 0.0 0.0 TEMP DEG K 298.15 298.15 298.15 298.15 DENSITY= 936.29 2.1803 521.3 1.2436.3 -1299.5 2.0698 24.401 0.3195 1.3421 488.3 4.974 STATE 4493 1-773 255-1 247-7 000-0 **** 27 900 .000 -200 000 .000 -326 300 .000 -287 900 .000 REACTANT CAL /MOL -164 700 .000 0.0 ENERGY EXIT 259.47 7.8675 717.4 3.2613-3 1235.2 24.401 0.3363 1.3195 1.690 246.9 236.1 567.9 4493 20.000 WT FRACTION (SEE NOTE) 0.951500 0.004000 0.007500 0.030000 0.095000 97.626 20.910 904.2 6.8770-3 -1170.9 2.0698 24.401 0.3519 1.3011 633.1 3.469 4493 1.603 238.2 223.9 10.000 0.0 EXIT 36.083 56.575 1132.5 1.4855-2 -1088.6 2.0698 24.401 0.3681 1.2841 703.9 2.888 1.485 226.7 207.3 6655 2.0000 EQUIVALENCE RATIO= 1.6846 EXIT 1,3435 1519,43 2244,3 2,0132-1 -650,1 2,0698 24.401 0.4134 1.2453 975.9 0.699 4493 0.498 183.9 69.5 1.1000 24.401 0.4152 1.2440 992.6 0.437 EXIT 1.1244 1815.57 2324.2 2.3229-1 -617.0 2.0698 0.316 230.5 44.2 6644 1.5000 10.27200 EXIT 1.0088 2023.61 2374.1 2.5346-1 0.4163 1.2432 1002.9 0.119 2.0698 704.3 12.2 4493 0.087 5.0000 24.401 0 1.00000 4.00000 3.00000 2.63580 PERCENT FUEL = 100.0000 EXIT 1.0021 2037.01 2377.2 2.5481-1 -595.0 2.0698 24.401 0.4164 1.2432 1003.5 0.059 10.000 4493 0.043 1400.6 6.0 z z000 THROAT 11.8009 11.33.54 2117.9 1.5915-1 -702.2 2.0698 24°401 0°4102 1°2477 948°9 1°000 11.00000 14.00000 1.00000 1.00000 4493 0.693 174.3 0000-1 Н 7.36400 CHEMICAL FORMULA C 6.00000 H 7.3 C 1.00000 C 12.00000 H 11.0 C 18.00000 H 14.0 C 18.00000 S 1.0 C 1.00000 C 1.00 CHAMBER 1.0000 2041.37 2378.2 2.5525-1 0.4164 1.2431 1003.7 0.0 2.0698 -594.6 24.401 * 30000.0 PSIA 0.0 T, DEG K RHO, G/CC H, CAL/G S, CAL/GS, (K) CP. CAL/(G)(K) GAMMA (S) IVAC LB-SEC/LB SON VEL,M/SEC CSTA4, FT/SEC 0000 ¥ 0 = 1/0 H P. ATM ž Puel Fuel Fuel Fuel Fuel Fuel 96/19 ۲

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2) [30,000 psi]TABLE 33.

					0.4516				
20	0.00007	CH4	0.00013					0.00010	
C02	0.11021	CAO(S)	0.00026		0.0002			2100	
z	0.00014	FC0	0.00002	HNCO	0.00003	3 H2		3531	
0	0, 18964	H2S	0.00074		0.0004			6160	
	0.00023	NACN	0.00005		0000			0140	
	0.00003	SH	0.00002						
S	Ų	¥3	CH2	C H3		CNN	CN2	CS	C 52
	H2 J	C 2H2	2.2H4	C 2H6		C2N2	C 20	C3	C 305
	2	1717	CALCI	(TAC)		CAC03(S)	CAC03(S)	CAD(L)	CAO
Ŧ	CAD2H2(S)	CAS(S)	CAS04(S)	CA2	HNO	HN02	HND3	H02	H 20(S.)
(1)	H202	H2504(L)	H2504	z		Ĭ	NH2	Q	N02
	N2H4	N20	N204	N 205		NA(S)	NA(L)	NACN(S)	NACNILI
	NAOH (S.)	NAOH (L.)	NA 0 2 (S)	N A2		NA2C03(S)	NA2C03(L)	NA2C2N2	NA20(S)
20(5)	NA20 (L.)	NA20	NA 202 (S)	NA 202(S)		NA2504(S)	NA2504(S)	NA2S04(S)	NA2S04(L)
NA2534	0	20	63	S (S)	S(L)	S	NS.	20	205
6	25	8.20	SB						

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF DXIDANT IN TOTAL OXIDANTS

TABLE 34. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2) [40,000 pst]

PC = 4000000 PSIA	SIA											
CHEMI FUEL C 6.0 FUEL C 1.0	CHEMICAL FORMULA 6.00000 H 7 1.00000	HULA H 7.36400	N 2.64580		0 10.27200		5 0	MT FRACTION (SEE NOTE) 0.951500	ENERGY CAL/MOL -164700.000	ST	TEMP DEG K 298-15	DENSITY G/CC 0.0
O O Z C		H 11.00000 H 14.00000 S 1.00000	•	000				0.007500 0.030000 0.030000	27 900 000 -200 000 000 -326 300 000	, , , , , , , , , , , , , , , , , , ,	298.15 298.15 298.15 298.15	
0/F= 0.0	.	1.00000 PERCENT FUEL	0 3.00000 L= 100.0000		JI VALENCE	EQUIVALENCE RATIO= 1.6846		0.002000 PHI= 0.0	-287900.000	_	298.15 ITY= 0.0	0.0
	CHAMBER	THRDAT	EXIT	EXIT		FXA	FX	Ex 11	<u>.</u>	÷		
PC/P	1.0000	1.8008	1.0021	1.0088	1, 1243	1,3435	36.066	97.566	259.27	935,37		
P. AIM	2721.83	1511.48	2716.03	2698.15	2420.81	2025.96	75.468	27.897	10.498	2.9099		
To DEG K		2119.0	2378.2	2375.1	2325.2	2245, 3	1133.6	905.2	718.3	522.1		
KHU, 6/CC		2-1221-1	3.3977-1	3.3797-1	3.0973-1	2.6844-1	1.9806-2			1.6580-3		
H. LAL/G	-594.6	- 702.2	-595.0	-596.3	-617.0	-650.1	-1088.6			-1299.6		
S. CAL/(G)(K)	2.0463	2.0463	2.0463	2.0463	2.0463	2.0463	2.0463	2.0463		2.0463		
M. MOL HT	24.412	24.412	24.412	24.412	24.412	24,412	24.412	24 .412	24.412	24.412		
CP. CAL/(G)(K)	0.4164	0.4103	9.4164	0.4163	0.4153		0.3681	0-3520	0.3364	0.3195		
GAMMA (S)	1.2430	1.2475	1.2430	1.2430	1.2438	1.2452	1.2819	1.3008	1.3192	1.3419		
SUN VELOM/SEC	1003.6	6.8%	1003.4	1002.8	992.5	975.8	704•1	633.3	568.1	488.5		
MACH NUMBER	0.0	1.000	0.059	0.119	0.437	6690	2.888	3.468	4.076	4.972		
AE/AT		1.0000	10.000	5.0000	1.5000	1.1000	5.0000	10-000	20,000	50,000		
CSTAR, FT/SEC		76 77	7677	7677	7677	7677	7677	7677	7077	7677		
CF.		6.694	0.043	0.087	0.316	0.498	1.485	1.603	1.691	1.773		
IVAC LB-SEC/LB		174.3	1400.3	704.3	230.5	183, 9	226.7	238.3	246.9	255.2		
15P. LB-SEC/LB		96.8	0.9	12.2	44.2	69.5	207.3	223.9	236.1	247.7		

TABLE 34. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2) [40,000 psi]

MOLE FRACTIONS

	NDI T 10NS	CS2 C302 CAO H20(S) NG2 NACN(L) NA20(S) NA20(S)
0.00010 0.00010 0.13495 0.10914 0.00141	0.50000E-05 FOR ALL ASSIGNED CONDITIONS	CS C3 CAO(L) HO2 NO NACN(S) NAZCZNZ NAZCZNZ S0
	00E-05 FOR AL	CN2 C 20 C ACO 3 (S) H NO3 N H 2 N A 2 (C) (S) N A 2 (C) (S) S N
7 COS 3 H H 4 H2 4 N2		CNN C 2N2 C ACQ 3 (S) H NO 2 N H N A 2 CQ 3 (S) N A 2 S O 4 (S) S
0.45147 0.00023 0.0004 0.00054 0.00054	NS WERE LESS	CV CZ N CA HVO NCO N3 NA 202H2 S(L)
CO CAO2H2 HNCO NH3 NAH	BUT WHOSE MOLE FRACTIONS WERE LESS THAN	CH3 CZH6 CAIL) CA2 N 205 N A2 N A2 N A2 S (S)
0.00023 0.00026 0.00002 0.00074 0.0006		CH2 C2H4 CAIS) CASO4(S) H2SO4 N2O4 NAO2(S) NA 2O2(S) O3
CH 4 CA D(S) HC 0 H2 S NA CN	H WERE CONSI	CH CZHZ CA(S) CAS(S) HZSO4(L) NZO NAOH(L) NA 20 02
0.00010 0.11044 0.00018 0.18969 0.00021	ADDITICNAL PRODUCTS WHICH WERE CONSIDERED	C 2H C 2H C 56 C 402 H 2 (S) H 20 2 N 20 4 N 4 20 6 N 4 20 6 N 5 2 6 S 2
CH20 CO2 HCN H20 NA	ADDIT I CNAL	C(S) C2 C4 C4 C4 C4 C4 C4 M03 N03 NA20(S) NA20(S)

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 35. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2)
[50,000 pst]

DENSITY 6/CC 0.0 0.0 0.0 0.0		
TEMP DEG K 298.15 298.15 298.15 298.15	TY= 0.0	
STATE 00 S 00 S 00 S	REACTANT DENSITY=	EXIT 934-36 3-6413 523-0 2-0721-3 -1299-8 2-0282 24-424 0-3195 1-3416 468-7 4-970 50-000 4494 1-774 255-2
EN ERGY CAL/HOL -164700.000 0.0 27900.000 -200000.000 -28300.000	REACT	EXIT 259.06 13.134 719.6 5.4344-3 2 -1235.6 2.0282 2.0282 2.0282 2.0282 1.3190 568.3 6.075 4.996 1.691 2.66.9
KEE NOTE) 0.95 1500 0.00 7500 0.00	PHI= 0.0	EXIT 97.500 34.895 906.3 1.1460-2 -1171.0 2.0282 24.424 0.3521 1.3005 633.5 3.467 10.000 4494 1.604 238.3
		EXIT 36.048 94.382 1134.8 2.4136.2 -1086.7 2.028.7 2.028.7 1.2836 1.2836 1.2888 5.0000 4494 1.485
	EQUIVALENCE RATIO= 1.6846	EXIT 1.3434 2532.56 2246.4 3.357-1 2.0282 2.4.424 0.4135 11.2450 975.7 0.699 1.1000 4494 0.498 183.9 69.5
n 10.27200	I V AL ENCE	EXIT 1.1243 3026.06 2326.3 3.819-1 2.0282 24.424 0.4153 11.2436 992.4 0.437 1.5000 4494 0.316 230.5 4422
		EXIT 1.0088 3372.73 4.2376.2 4.2246-1 2.0282 2.0282 2.0282 1.2428 1002.7 0.119 5.0000 4494 0.087 704.5
N 2.63530 N 1.00000 N 4.00000 D 4.00000	L = 100.0000	EXIT 1.0021 3395.06 2379.2 4.2473-1 2.0282 24.424 1003.3 0.059 10.000 4494 0.043 1399.6
ULA 7,364011 11,00000 14,00000 1,00000	PERCENT FUEL=	THROAT 1.8006 1889.50 2.6527-1 2.6527-1 2.0282 2.0282 2.0282 2.0282 1.2473 948.8 1.0000 1.0000 4494 0.693 174.3
COOO HE HERE		CHAMBER 1.0000 3402.28 4.2545-1 -594.6 2.0282 2.0282 1.2429 1.2429 1.03.5
PC = 50000.0 PSIA CHEMICAL FUEL C 6.00000 FUEL C 1.00000 FUEL C 12.00000 FUEL C 18.00000 FUEL C 18.00000	0/F= 0.0	6) (K) 1/SEC 1/SEC 1/SEC 1/SEC 1/SEC
PC = 5 FUFL FUEL FUEL FUEL FUEL		PC/P P, AIM T, DEG K RHO, G/CC H, CAL/G S, CAL/G) G M, MJL WI CP, CAL/G) G GAMMA (S) SON VEL, W/S) SON VEL, W/S CSTAR, FT/S CF CSTAR, FT/S

2 THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of [50,000 psi] TABLE 35.

C 2 C 4 C A D H H 2 D (L) N D 3 N A 2 D N A 2 S D 4 S D 3 0.50000E-05 FOR ALL ASSIGNED CONDITIONS CS2 C302 CAO H20(S) N02 NACN(L) NAZO(S) NAZO(S) 0.00023 0.00023 0.00064 0.00067 NACC 2N2 NACC 2N2 NACS 04 (S) SO CS C3 CAO(L) H02 9 CO CAO2H2 HNCO NH3 NAH CN2 C20 CAC03(S) HN03 NN42 NA4(L) NA2C03(L) NA2C03(S) SN ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.00035 0.00025 0.00002 0.00074 0.00008 NA (S) NA 2CO3 (S) NA 2SO4 (S) S CNN C2 N2 CA CO3 (S.) HN O2 NH CH4 CAO(S) HC0 H2S NACN SH CN C2N C2N HNO HNO NCO N3 NA2CO3(S) NA2CO3(S) 0.00001 0.11071 0.00022 0.18976 0.00018 CH2 C2H6 CA(L) CA2 N N2O5 NA2 NA2 S(S) CH C2H4 CA(S) CASO4(S) H2SO4 N2O4 NAO2(S) NA 2O 2(S) CH3 CC02 HCN HCO NA 0.00012 0.00010 0.00009 0.13455 0.10909 HOLE FRACTIONS CA02H2 (S) H202 NZH4 NAOH(S) NAZO(L) H H2 N2 NAOH C 24 C 24 C 34 CH20 COS

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 36. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2)
[60,000 psi]

DENSITY 6,0 0.0 0.0 0.0 0.0		
TEMP DEG K 298.15 298.15 298.15 298.15 298.15	SITY= 0.0	
4GY STATE MGL S 0.00 S 0.00 S 0.000 S 0.000 S	REACTANT DENSITY=	EXIT 933.30 4.3745 524.00 -1300.00 2.0134 2.0134 0.3196 1.3413 4.99.00 4.968 50.000 4494 1.774 255.2
ENEI CAL, -16470 -20000 -32630	REA	EXIT 258.81 15.775 120.5 6.520.2-3 -1235.6 2.0134 24.437 0.3365 1.3186 568.6 4.073 20.000 4494 1.691 247.0
MF FRACTION (SEE NOTE) 0.951500 0.007500 0.030000 0.005000	PH1= 0.0	EXIT 97.432 41.904 907.6 1.3750-2 -1171.1 2.0134 24.437 0.3522 1.3002 633.6 1.466 1.604 1.604 224.0
3 0		EXIT 36.029 113.32 1136.1 2.9704-2 -1088.7 2.0134 2.0134 1.2834 10.2834 10.2834 10.485 2.867
	EQUIVALENCE RATIO= 1.6846	EXIT 1.3434 3039.16 2247.6 4.0269-1 2.0134 24.437 0.4136 1.2448 1.2448 1.2448 1.2448 1.2448 1.2448 1.2448 1.2448 1.2448 1.2448 1.2448 1.2448 1.2448 1.2468 1.2494 1.2494
0 10.27200	JIVALENCE	EXIT 1.1243 3631.30 2327.5 4.6464-1 2.0134 24.437 0.4154 1.2434 992.3 0.437 1.5000 4494 0.316 230.5 44.2
		EXIT 1.0088 4047.23 2377.3 5.0099-1 2.0134 2.0134 2.0134 0.4165 10.24.65 10.24.65 10.24.65 0.119 5.0000 4494 0.087
N 2.63580 N 1.00000 0 4.00000 0 3.00000	il = 100,0000	EXIT 1,0021 4074.02 2380.4 5,096.9-1 2,0134 2,0134 0,4165 11,2426 10,032 0,059 10,000 4494 0,043 1399.1
RMULA H 7.36400 H 11.00000 H 14.00000 S 1.00000	PERCENT FUEL =	THROAT 1.8005 2267.54 21833-1 -702.1 2.0134 24.437 0.4104 1.2471 946.7 1.0000 4494 0.693 174.3
		CHAMBER 1.0000 4082.74 2381.4 5.1057-1 2.0134 2.0134 0.4165 1003.4 0.0
PC = 60000.0 PSIA CHEMICAL FUEL C 1.00000 FUEL C 12.00000 FUEL C 18.00000 FUEL C 18.00000 FUEL C 18.00000	C/F= 0.0	K CC (G)(K) WT -/(G)(K) S) MNSEC MRER FT/SEC
ה " " " " " " " " " " " " " " " " " " "		PC/P P, ATH T, DEG K RHO, G/CC H, CAL/G S, CAL/(G)(CP, CAL/(G)(GAMMA (S) GAMMA (S) GAMMA (S) GAMMA (S) GAMMA (S) CSTAY, FT/S CSTAY, FT/S CF

TABLE 36. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2)
[60,000 psi]

MOLE FRACTIONS

	CONDITIONS	C 2 C 4 C A 0 H H 20 (L 1) N 2 H 4 N A 20 (L 1) U 5 S 2	
0.45103 0.00023 0.00005 0.00001 0.00009	FOR ALL ASSIGNED CONDITIONS	C S 2 C 3 0 2 C A 0 C A 0 H 2 0 (S) N A 0 N A 2 0 4 S 0 3	
	0E-05 FOR AL	CS C3 CAO(L) HD2 NO2 NACO(L) NAZO(S) NAZO(S)	
CO CAD2H2 HNCO NH2 NACN SH	THAN 0.50000E-05	CN2 CZO CACO3(S) HNO3 NO NACON(S) NACCN2 NACCN2 SO	
0.00050 0.00025 0.0003 0.00075 0.00017	HOLE FRACTIONS WERE LESS THAN	CNN C2N2 C4CG3(S) HN 02 NA 1L) NA 2CG3(L) NA 2SG4(S) SN	
CH4 CAO(S) HC0 H2S NA OH	HOLE FRACTION	CN C2N CA HNO NCO NACO NACO3(S) NACCO3(S) NACCO3(S)	
0.00001 0.1100 0.00027 0.18984 0.10905	BUT WHOSE	CH2 C2H6 CA(L) CA2 N N3 NA2C3(S) NA2O2H2	
CH3 CC 2 HCN H20 NAOH	WERE CONSIC	CH CZH4 CA(S) CA(S) CASO4(S) HZSO4 NZO5 NA2 NAZOS NAZOS(S) S(S)	•
0.00015 0.00010 0.00008 0.13410 0.00079	ADDITIONAL PRODUCTS WHICH WERE CONSIDERED	C C C C C C C C C C C C C C C C C C C	
CH20 COS COS H H2 NH3 NAH	ADDIT IONAL	C(S) C2H C5 CAO2H2(S) H2O2 N2O NAOH(L) NA2O 02	

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF DXIDANT IN TOTAL OXIDANTS

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